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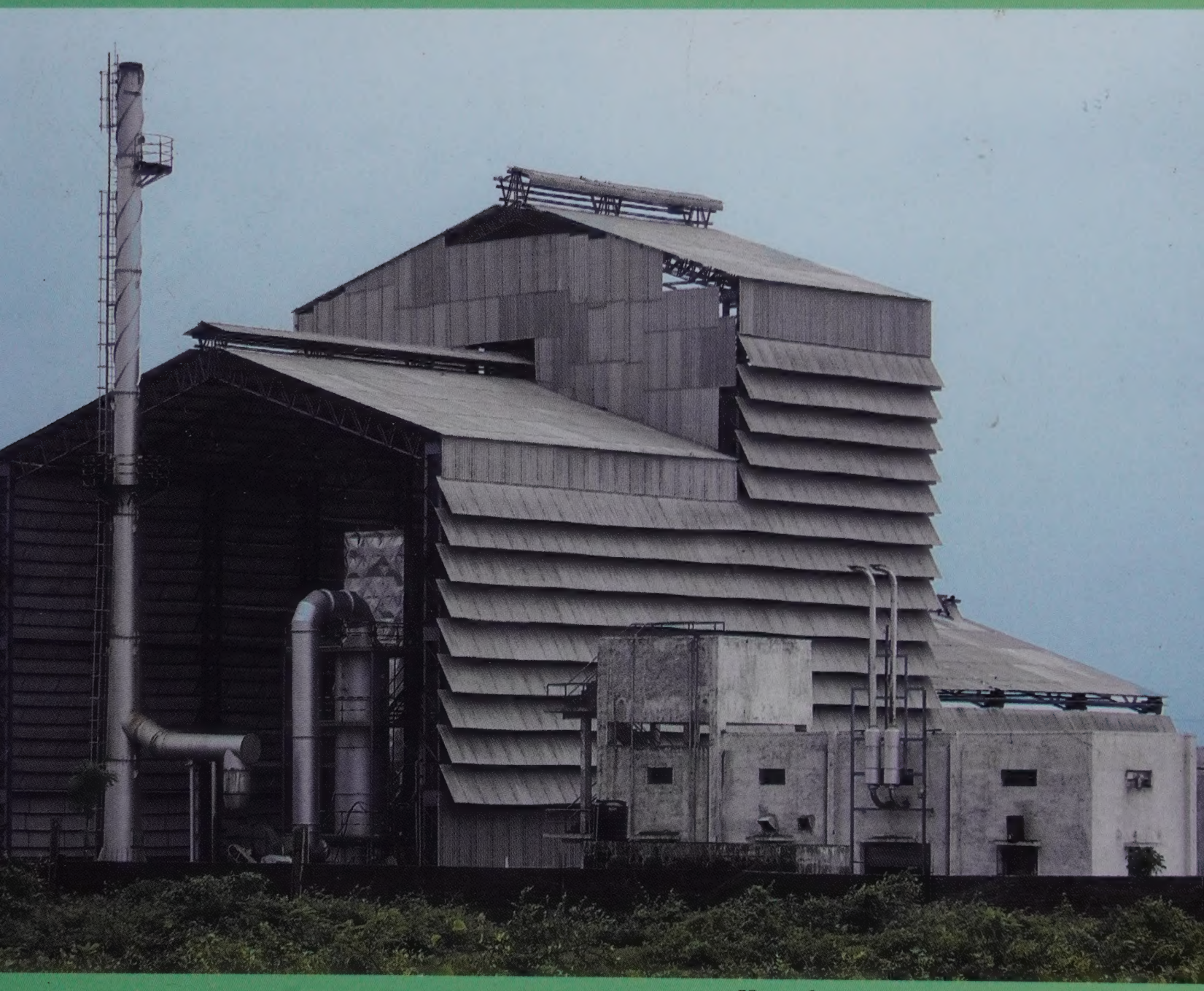
Waste Minimisation

– A training manual –



Hazardous waste incinerator at Taloja

D. B. Boralkar and A. K. Mhaskar

Foreword by Dr. V. Rajagopalan
Chairman, Central Pollution Control Board

This is the first training manual on waste minimisation available in the country. And it has appeared just at the right time. Everywhere people are objecting to the siting of hazardous waste disposal facilities in their neighbourhoods. Industry managers and government authorities are at their wits' end.

Dr. Dilip B. Boralkar and Shri A. K. Mhaskar suggest that serious efforts at waste minimisation hold the only key to get out of the present impasse.

The authors argue that waste minimisation is not an unnecessary or unproductive expenditure. On the contrary, if tackled intelligently as an economic project, it can save costs, generate raw materials and at the same time protect the environment.

Waste Minimisation is a source book of rich and practical ideas on how to go about minimising wastes in different industries. It is bound to be of immense use to captains of industry, managers of industrial plants, pollution control officials, academics and environmentalists at large.

THE OTHER INDIA PRESS

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– A training manual –

Dilip B. Boralkar
A.K.Mhaskar

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Chairman,CPCB

Other India Press
Goa, India

Waste Minimisation

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Cover: Inset photograph is of the hazardous waste incinerator at Taloja in Maharashtra

Note from the authors

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Dedication

To

Prof. M. G. K. Menon
who has been a constant source of inspiration for me

Dr. D. B. Boralkar

To

My 94-year old mother,
Who still reads the newspaper everyday,
Who still loves Mother Earth,
Who still tells me to preserve it
For Isha, her little, great grand-daughter

Ashok Keshav Mhaskar

डा. वी. राजगोपालन, भा.प्र.से.
अध्यक्ष

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पर्यावरण एवं वन मंत्रालय

Central Pollution Control Board
(A Govt. of India Organisation)
Ministry of Environment & Forests
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FOREWORD

Waste is a result of inefficient process. What we need is optimum and effective utilisation of raw material resulting in waste minimisation. Process must take into account the feasibility of putting waste to use either as secondary source of raw material or as fuel for power generation.

There are about 45,000 chemicals and, every year, more chemicals are being added. To avoid adverse impacts of wastes on environment and health, we need to adopt the concept of 'cradle-to-grave-to-rebirth'. Waste reduction and recycling are essential. This is well elucidated in the Sanskrit *shloka* as below:

अमंत्रम् अक्षरम् नास्ति । नास्ति मूलम् अनौषधम् ॥
अयोग्यम् वस्तु नास्त्येव । योजकस्तत्र दुर्लभः ॥

(There is no alphabet, which potentially does not have a power to create magic. There is no plant-root that does not contain some medicinal value. There is no thing like a useless waste. What is rare is a designer and planner to shape the things properly.)

'Waste Minimisation' book by Dr. Dilip Boralkar and Shri A. K. Mhaskar is an excellent compilation of information on how to avoid or minimise the environmental problems by resorting to waste minimisation practices in manufacturing processes. The book also provides tips to 'leap-frog' especially, prioritisation, vendor selection, predictive maintenance, efficiency tricks and designing an appropriate training manual.

I am sure this book will be useful to all concerned in the field of environment protection in general and waste minimisation in particular.

V. Rajagopalan

(V. Rajagopalan)
Chairman
Central Pollution Control Board
June 5, 2006

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PREFACE

If we could rewind the wheel of time by about fifty years and be back in the pre-Independence era – a period of insignificant production and insignificant pollution as well – this book would have no justification to exist. The state of affairs, however, has changed drastically since then what with high national productivity, large-scale consumerism, enhanced purchasing power, low tolerance with regard to discomfort and large mountains of unwanted wastes. Demands for waste minimisation strategies have firmly arrived. Industry managers and pollution enforcement authorities are looking for advice and guidance, but little literature is available on the subject.

Chapter 1 of this manual on how to minimise industrial wastes begins with an overview of production and pollution over the past five decades.

Humankind down stream and down wind of industrial plants will remain happy and untroubled, if pollution is kept within the absorptive capacities of Nature. Chapter 2 therefore goes into the paramount need to engage in efforts to minimise and reduce wastes, and to aim at zero discharge.

Chapter 3 provides a preparatory drill to establish a framework for our thinking about this problem and narrates a number of possible ways of reusing waste.

Chapter 4 tells us how right-thinking industry logically chalks out a waste minimisation programme in its premises while chapter 5 proposes actual implementation, step by step, of a well-designed waste management programme and suggests a procedure to assess its results.

Successful case studies are always needed to generate a spark in the minds of our readers: these are reported in chapter 6.

Credit for controlling routine wastes over 364 days will get invariably washed out or discounted if even the smallest, momentary leak or spill occurs on the last remaining day. Logically, 'Safety First' should have indeed come in chapter 1. However, it has been separately treated in chapter 7.

This manual will meet the difficulty of non-availability of training material to guide industry's staff and employees on waste minimisation. It was thought necessary to assemble, compile and relay such information in one place. Inputs from many friends and from workshop materials and proceedings have been freely used in this book. As the number of sources of information is very large, writing this book became less burdensome. However, precisely for the same reason, acknowledging every one by name here has become that much more difficult. We acknowledge our debt to many. The support provided by Ms. Vinita Dhupkar is gratefully acknowledged.

Dilip B. Boralkar
15 August, 2006

A. K. Mhaskar

1

THE GENERATION OF WASTE

1.1 Fifty Years of Pollution

In the last fifty years, post-independence, India has made vast strides in several fields. The standard of living has risen, production of goods and availability of services have been greatly enhanced and the variety of merchandise available is mind-boggling. Statistics tell us that while there were 0.3 million vehicles in India in 1951, today the number has increased more than 150 times. This is not surprising news because about 2.5 million vehicles are manufactured every year in the country. Similar is the case with statistics on diverse subjects such as population, life expectancy, number of industries, number of cities and towns, production of food, fertiliser, pesticides, expenditure incurred on health, water supply, quantum of energy produced and consumed, etc. The quantum of electrical power produced in the entire country at the time of independence is now generated today in the capital city of Delhi alone. India presently is the fourth largest cement producing country in the world, after USA, Japan and China. In fact, the country today has sprung to tenth position in the world economy (US$691,876 million: 2004).

Statistics relating to a variety of subjects as available for the years 1973 and 1993 are given in table 1. A reading of the table shows higher trends in almost all the items. This is the silver lining, but there is a black cloud at the core. When we boast of increases in the production of goods and energy, we have encroached on natural resources, converting some part into unassimilated waste. Merchandise has increased not in proportion to the population, but several times higher, indicating a high degree of consumerism. Life expectancy is high which means that the needs per person have increased both in years and quantity.

Table 1: Indian economy (1973-1993) at a glance

#	Subject	1973	1993	% increase
1	Current GNP/capita USD	130	330	153.85
2	Population (million)	593	898	51.43
3	GNP (in Rs billion)	618.1	7745.8	1153.2
4	Export of goods and services (in Rs billion)	26.5	389.8	1371
5	Import of goods and services (in Rs billion)	29.8	350.4	1075.84
6	GDP at factor cost (in 1987 Rs billion)	1647	3991.4	142.34
7	Agriculture (in 1987 Rs billion)	694	1187.8	71.15
8	Industry (in 1987 Rs billion)	394.9	1126.3	185.2
9	Manufacture (in 1987 Rs billion)	248.5	690.3	177.8
10	Capacity to import (in 1987 Rs billion)	118.8	344.3	189.8
11	Employment (1987 = 100)	76.9	107.2	39.4
12	Earning as percent of value added (1987 = 100)	47.8	37.6	(-) 21.34
13	Value of export (in million dollars)	2923	21552.6	673.3
14	Value of import (in million dollars)	3210	22761.2	609.1
15	External debt (in million dollars)	10953.4	91781.4	737.9
16	Urban population % of total	20.7	26.3	27.1
17	Public expenditure on health (% GDP)	2.3	2	(-) 13.04
18	Life expectancy at birth	50.0	60.8	21.60
19	Infant mortality rate	145	80	(-) 44.83
20	Food production per capita (1987 = 100)	91.6	113.3	23.69
21	Labour force millions	235.46	341.46	45

The inferences one can draw from the above table – which spans the two middle decades since independence – are as follows:

1. Population has increased by 51.43 %, GNP by 153.85%. This increase is very high due to technological advancement. A major component of the increase in production is in the agricultural and industrial sectors. While higher production is welcome, there are unpleasant side effects too, namely increase in by-products and more waste generation. This trend will increase unless efforts for waste minimisation are made by all sectors.

2. Exports have increased by 1371%. This could be because the quality of Indian goods has improved and it is able to meet internationally acceptable levels. But it could also be because developed countries have preferred to outsource manufacture of those goods which create more waste during the production process.

3. Imports too have increased by 1075.84%, i.e., almost eleven times. In addition, our domestic production of goods has also increased. This shows that the domestic consumption of commodities has increased in India. This may indicate increase in the consumer's purchasing power, but it also shows increase in the exploitation of our natural resources and creation of more wastes in the form of spent packing materials.

4. Employment has increased by 39.40%, the labour force by 45%. However, this is fully offset by the increase in population (51.43%). Socio-economic status is also an environmental issue. It also makes one suspicious when one finds that earnings – as percent of value added – have dwindled by 21.34%.

5. The urban population has increased by 30.92%, which means our towns are overpopulated, leading to several environmental problems. Though people are migrating out of the villages, agricultural production has increased by 87.30%. This is possible only because of the use of agro-chemicals and mechanisation. This means more fertilisers and pesticides in our environment, depletion of water resources and more energy consumption to feed more people on lesser land.

6. Science has improved health statistics on two counts: the infant mortality rate has reduced by 44.83%, and life expectancy at birth has increased by about 21.60%. This means more goods will be required, which in turn means increase in corresponding wastes. Increase in public expenditure on health is a substantially high 110.73% and is partly attributed to the consequences of increase in pollution levels.

7. If external debt is taken as an indicator of development, it shows an increase of 737.9% over this span of 20 years, from 1973 to 1993. Is this sustainable?

If the statistics are examined more closely, production of most of the important chemicals such as H_2SO_4, nitrogen, oxygen, ethylene, lime, ammonia NH_3, NaOH, chlorine, phosphoric acid, propylene, Na_2CO_3, HNO_3, ethylene dichloride, NH_4NO_3, urea, vinyl chloride, benzene, ethylebenzene, CO_2 etc, has increased, indicating an average growth in all industries like electricals, chemicals, pulp and paper, transport equipment, food, beverages, tobacco, mechanical engineering, metals, textiles, leather and general manufacturing.

To sum up:

1. Industries have increased manifold, but growth in chemical industries is much higher. (This is true internationally too. In one decade, the ratio of growth rate of chemical industries to all manufacturing industries in UK was 1.9. The corresponding figures for Germany, France, Italy, the whole of the EEC, USA and Japan are 1.1, 3.2, 1.1, 1.7, 1.0 and 2.2 respectively.)

2. Growth in organic chemicals is very high, and this is a source of unassimilated wastes.

3. Chemicals meant for downstream usage result in cascading of wastes.

4. While export of chemicals has increased, it means increase in pollution in India.

Today, farming is generally more mechanised. Crops are provided with fertilisers and pesticides in a better way. The country can be fed despite fewer people working on the farms, while others migrate to the towns. Industry needs more labour and is capable of absorbing the migrants. Goods and passenger traffic has increased transportation requirements with attendant emissions, accidents and spillages. Colourful dyed packaging attracts consumers but this ends in a huge plastic waste load. New dwelling places rob the earth of its soil, sand, stones, wood and metals. Industrialisation and urbanisation have enhanced the standard of living, but the quality of life has certainly gone down. Previously water used to contain dissolved oxygen (DO), air could dilute gases, winds could dissipate them. It was possible to set up landfills in uninhabited lands as these were available in plenty. But when towns get converted to cities and cities

to metros, the distance between two neighbourhoods becomes very short and they are soon practically abutting each other. If there is a common river, safe distances between two riparian towns are no more maintainable. No point can be described as either 'upstream' or 'downstream'. The phenomenon of natural self-purification and re-aeration of streams and the possibility of released 'wastewater' restoring itself as 'water' after travelling some distance is now history. Water that becomes wastewater remains wastewater until it reaches the sea. The same is the case with solid waste. The age-old solution of 'throw away out of sight' worked earlier, but can no more be used simply because there is no land to 'throw on' and no land which is out of (somebody's) 'sight'. People are everywhere, and the earth has limited capacity to absorb the refuse of landfills.

All this has happened because anti-pollution laws have come too late and are not implemented to the desired degree even as of now. (In its order dated 14.10.2003 in writ petition No.657/1995, the Supreme Court concluded: 'The problem is not as much as the absence of rules as it is of implementation.')

We generally consider national productivity as our preferred indicator of growth and development. But it needs to be borne in mind that such productivity is not without generation of waste and pollution. It is, therefore, essential that those productivity indices should be preferred which also provide support to the generation of useful 'by-products' as well as waste minimisation.

Mankind has already produced about 45,000 chemicals and 1,000 new ones are said to be added every year. Every moment we are facing hazardous chemicals, hazardous wastes, hazardous processes or hazardous transport. After fifty years of independence, if we see more people on the road with mineral water bottles in their hands and masks on their faces, this can hardly be called progress.

Our environment is so fragile that industries and statutory authorities have to take responsible care. They should note that the very people demanding more products at one time, now demand and insist on a clean environment. Earlier, chemical engineers were needed only in manufacturing processes. Now they have to be involved in producing clean products and in waste minimisation.

There is only one solution finally and that is to minimise pollution. The idea may be phrased differently: for example, as waste minimisation or waste reduction or waste strength reduction; clean technologies or green technologies or pollution prevention (P2); environment-friendly technologies or low or no waste technologies or zero discharge, ('zero' here meaning something you can hardly measure).

The preference, naturally, will be reflected in the following order:

- No waste generation at all;
- If waste is generated, it is recycled (which means less need for fresh raw materials);
- Residual wastes will be reduced in volume and weight, and toxicity by treatment; and
- Disposal of treated residues should be so smooth that it does not adversely affect the recipient body (for example, discharge of treated effluent through an out fall diffuser).

We now have to make up for the time lost over the past 50 years.

1.2 The CPCB Action Plan for Pollution Control

The Central Pollution Control Board (CPCB) had formulated a Central Action Plan (CAP) in the last decade for the prevention, abatement and control of pollution especially related to the water and air components of the environment. The different focal points of the programme are detailed in table 2.

The schemes were of good design; they were implemented with vigour, and notes on performance were compared from time to time. The CPCB offered both technical pull and legal push to achieve CAP's objectives. If the progress, however, fell short of expectations, it was perhaps because both the forces of pull and push were limited or clearly insufficient.

Table 2: CPCB Action Plan focal points

#	Focal points	Present scenario
1	Sensitive area approach	Some areas in India were so highly polluted that unless extraordinary efforts were made, the impacts could not be minimized, e.g., Chembur in Mumbai (which had acquired the nick-name, 'Gas Chamber'). Three such areas were identified under this category.
2	Polluted river stretch	Some stretches of Indian rivers were so highly polluted that without concentrated efforts made, the impact could not be minimized, e.g., the river Ganga downstream of Kanpur, Allahabad or Varanasi. (Later other similar stretches were identified on the Yamuna, Gomati and Godavari rivers.)
3	Specific pollutants	Some pollutants were having such adverse impacts on people that unless urgent efforts were made, the impact could not be eliminated, e.g., mercury in chlor-alkali plants. (Later, H-acid production was also taken up.)
4	Specific industries	Some particular industries, by their very nature and scale, were potentially so highly polluting (of water and/or air) that without strong preventive measures, the impact could not be minimized, e.g., pesticide or electro-plating units. Seventeen such industries were identified in this area, and progress tracked via computerization.
5	Grossly polluting industries	851 industries were identified in the vicinity of rivers or lakes for concentrated efforts at pollution control.

In 2003, the Ministry of Environment and Forests (MoEF) summed up the situation as follows:

1. Out of 1551 highly polluting industries identified, 1351 had provided necessary pollution control facilities.

2. Out of 851 identified grossly polluting industries discharging effluent directly into rivers and lakes, 608 had installed pollution control systems to comply with the standards in force.

3. In the 17 industries categorised as highly-polluting, there were no defaulters in Andhra Pradesh, Bihar, Gujarat, Karnataka, Punjab, Rajasthan, Tamil Nadu, and in all the Union Territories.

4. In the 17 industries categorised as highly-polluting, there were no defaulters in the dyes, leather, pesticide, pharmaceutical and pulp-paper units. Only two alcohol making, molasses-based distilleries were identified as polluters and so was one single sugar mill.

5. Industries letting waste into rivers or lakes numbered 2026. With the yardstick changed, the defaulters in 1997 were 851 and the number had come down to five in three years. None of these defaulters were from any major industrialised states (including Tamil Nadu, which alone had 1657 industries in the list of 2026 industries).

Although the above remarks create a sense of 'feel good', the following observations in the same report bring home the point that more work is indeed necessary:

> The CPCB continued the monitoring of water quality. It is observed that pollution load is on the increase and the water bodies are being further polluted.'
>
> River water quality is assessed by the SPCB [State Pollution Control Board], CPCB and MoEF. In 1986, 15% of the observations had shown BOD values as more than 6 mg/l. This percentage increased to 18% in 2001. The data indicated that Maharashtra has the highest pollution levels in terms of organic pollution, which is mainly industrial in nature. The report estimated that in the country, 22,900 MLD of domestic wastewater are generated from urban centres as against 13,000 MLD of industrial effluents. The treatment capacity available for domestic wastewater is only 6,000 MLD (or 26.20%) as against 8,000 MLD for industrial effluents (or 61.54%).'

It may thus be seen that when 5,000 MLD industrial effluents are going untreated into the environment, how can these above referred inferences of MoEF be relied upon in respect of industries falling either in the 17 highly polluting categories or grossly polluting industries located near rivers and lakes. Further, although a comparison of river water quality is made, this is not a significant comparison as 'more than' does not really tell us the real pollution level.

The same report gives information on water quality in the river Yamuna's 22 km stretch near Delhi. When the river shows an average BOD of 1.5 mg/l upstream and a rise to 41.3 mg/l on an average, even reaching to 77.0 mg/l, this 77 mg/l too will be shown as 'above 6', which indeed does not describe the situation. In fact it misguides. (The same can be said about the river Krishna, where TDS increases nearly five times between its origin and the state border.)

1.3 MoEF'S CREP Charter 2003 and Other Efforts

A fresh attempt was made by the Central Government to bring about the prevention, abatement and control of pollution through the Corporate Responsibility for Environmental Protection (CREP) Charter 2003.

However, only limited success was achieved here as well in spite of the good intentions of the government and the CPCB.

MoEF has taken the following initiatives in this regard:

1. **Waste minimisation or cleaner production**: The objective of the scheme is to assist small and medium scale industries to adopt cleaner production processes. Establishing waste management circles (just like quality circles) in clusters of SSI is encouraged and so far 115 such circles have been established. This is taken up under a World Bank scheme known as the Industrial Pollution Prevention Programme (IPPP). So far, more than 200 options have been obtained by these efforts.

2. **VOCs and HAPs** (volatile organic compounds and hazardous air pollutants): The concept exists on the lines of those already prevailing in the developed countries and this is being discussed and studied.

3. **Chemical safety**: There are 1460 MAH (Major Accident Hazard) units and 1395 on-site plans have already been designed in consultation with them.

4. **Hazardous waste**: As per the 2003 assessment, 13,011 units generated 4.4 million tonnes of hazardous waste. The States of Maharashtra, Gujarat and Tamil Nadu alone account for over 63% of the total hazardous waste generated. Writ Petition No.657/1995 (filed by the Research Foundation for Science, Technology and Natural Resource Policy versus the Union of India) and Writ Petition No.967/89 (filed by Indian Council for Enviro-legal Action against the Union of India) are both pending in the Supreme Court (SC).

5. **A Grievances Cell** has been constituted to ensure timely redressal of public complaints regarding environment problems. In one year alone, 390 such complaints were received from the general public.

1.4 The Supreme Court's Directions on Hazardous Waste

1.4.1 Definitions

Hazardous waste was first defined in the Hazardous Waste (Management and Handling) Rules, 1989 under Rule (3)(i), namely, as the scheduled list of 18 categories. The schedule covered the wastes broadly. However, in order to harmonise these with the Basel Convention, it was decided to modify the definition. Accordingly, the rules were revised in 2000 to constitute three schedules: one, depending on the nature of the industry and its processes; another, on the concentration levels of substances obtained by analysis of the waste; and a third, depending on the characteristics of the waste. The Rules were revised again in 2003 with three similar schedules, in addition to considerations of import and export of waste.

The USA rules define 'hazardous waste' as 'a solid or combination of solid wastes which, because of its quantity or concentration or physical, chemical or infectious characteristics may cause, or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed.'

The rules further explain that a 'mixture of non-hazardous solid waste and listed hazardous waste is legally a hazardous waste' [section 262.3 (a)(2)(iii)].

In the same rules, some wastes are exempted from the definition of hazardous waste: for example, nuclear waste, household waste, coal combustion waste, fertilisers, drilling muds, mining, cement dust, and small quantity generators (SQG). These are exempted because they are covered by other statutes. Similar (though not identical) is the case in Indian law.

The USA rules define the characteristics of hazardous waste as follows:

> 'A waste is hazardous if it exhibits one or more of the following characteristics, namely, ignitability (where the flash point is lower than 140 ^{0}F, and flash point is defined

as the lowest temperature to which a material can be heated to give off sufficient vapours to form ignitable mixture with the air near the surface of the material), corrosivity (where pH of the material is lesser than 2 and more than 12.5), reactivity (i.e. where it is normally unstable), or extraction potential (EP) toxicity.'

1.4.2 The Menon High-Powered Committee Report

The Supreme Court in 1997 in Writ Petition No.657 of 1995 appointed a High Powered Committee on Hazardous Wastes (HPC), headed by Dr. M. G. K. Menon. The HPC submitted its report to the apex court after three years of work.

The HPC report is a very studied document and industry managers will be benefitted by reading it. Some salient observations from the report are summarised below for the ready reference of readers (*the full report is at www.cpcb.nic.in/hpcreport/index.htm*):

1. Waste generation: The total number of industrial units generating hazardous waste in India are in the region of 13,011. The total quantity of hazardous waste generated is 2,611,717 TPY. Out of this 6.27% is recyclable, while another 7.05% is incinerable (which is, in a way, reusable for energy).

2. Documentation, compilation and statistics relating to hazardous wastes are poorly maintained. For example, the figures given by MoEF and by Rajasthan SPCB are substantially different for the same classes of wastes, as shown in table 3 below:

Table 3: Hazardous waste quantities in Rajasthan

Waste particulars	As per MoEF, TPY	As per SPCB, Rajasthan TPY
Recyclable	9,697	52,578
Incinerable	17,587	6,747
Disposal	95,023	81,285
Total	**122,307**	**140,610**

3. The majority of hazardous wastes are classified in five categories, namely, phenols, acid/alkali slurry waste, waste containing water-soluble compounds of heavy metals, off-specification discarded products and waste oil emulsions. These constitute respectively 57, 13, 8, 6, 5%, totalling 89%.

Table 4: Principles of environment law in India

#	Principle	Relevant Rules	Suggestions
1	**The Source Reduction Principle** – Generation of waste should be minimized in terms of quantity or potential to cause pollution	Rule 5(8)(ii)	An undertaking of this kind should be sought, not only at the time of grant of authorization but also at the time of renewal of authorization.
2	**The Integrated Life Cycle Principle** – Substances and products should be designed and managed in such a way that minimum environmental impact is caused during their generation, use, recovery and disposal	Under entry 6 and 7 of Form I, information on the product life cycle is sought	No provision in the rules to promote this principle, except for the one cited
3	**The Precautionary Principle** – Preventive measures are taken, considering the costs and benefits of action and inaction, when there is a scientific basis, even if limited, to believe that release into the environment of a substance, waste or energy is likely to cause harm to human health or the environment	No mention	Needs to be included
4	**The Integrated Pollution Control Principle** – The management of hazardous waste should be based on a strategy that takes into account the potential for cross-media and multi-media synergistic effects.	No mention	Needs to be mentioned, as compatibility of different wastes needs to be ensured in final disposal fields
5	**The Standardization Principle** – Standards need to be provided for the environmentally sound management of hazardous waste at all stages of their processing, treatment, disposal and recovery.	The rules in general seek to achieve this in some manner	
6	**The Proximity Principle** – The disposal of hazardous waste must take place as close as possible to its point of generation, recognizing that economically and environmentally sound management of hazardous waste will not be achieved if specialized facilities are located at a distance that is too far from the point of generation	No such provision	

7	**The Precautionary and Polluter Pays Principles** – The potential polluter must act to prevent pollution and those who cause pollution must pay for remedying the consequences of that pollution	Rule 16	Implementation of this principle is problematic
8	**The Principle of Public Participation** – At all stages, waste management options are considered in consultation with the public and the public has access to information concerning the management of hazardous waste	Rule 8(5)(6) which concerns public hearing for location and setting up of disposal sites	Needs to be included in some form while granting/ renewing authorization, enabling the public especially to access the data base of the concerned authorities. No public consultation is envisaged in the export-import process.

4. SPCBs and MoEF seem to have collected the data mechanically, as a ritualistic formality and merely to fulfil legal and bureaucratic requirements, rather than as part of a genuine effort to monitor the real situation. As a result, the data can hardly be used to plan strategies either for intelligent management or for reduction of such wastes.

5. Common TSDFs: Total identified disposal facilities are 89, out of which 30 are notified.

The HPC Report has compiled the principles of environmental laws generally enunciated by the courts. These are worth noting for the benefit of our readers and are tabulated conveniently in table 4.

The HPC was not restricted by tunnel vision and studied the developments in other regions of the world.

1. It noted that internationally there are two concepts – 'clean production' and 'cleaner production'. This requires going beyond the modification of present process in use. But if we do not insist on clean production process for new industries, then even a decade from now we shall be where we are. For this reason, it is imperative that the government declares and takes steps to ensure that expansion of existing hazardous waste generating industries and new industries of this nature follow the basic parameters of clean production. New

industries must be subjected to most stringent public disclosure rules regarding emissions, process, raw materials, hazard potential and mitigation scenarios.

2. The Massachusetts Initiative on Clean Production – The HPC referred to the Toxic Use Reduction Act (TURA) passed by the Commonwealth of Massachusetts in 1989, which is an unusual legislation. Section 11 requires the industries to demonstrate their commitment to toxic reduction. Section 19 levies fees on all the industries that use toxic materials.

In the first five years of implementation, toxic raw material use dropped by 20 percent, by-products generation dropped by 20%, in 55% of industries cost was saved by 67% and workers' health and safety cost saved by 66%. For the state, it required US$77 million for implementation of the TURA Act, but the initiative resulted in total monetised benefit of US$91 million. The HPC felt that this is feasible in India too.

3. Cleaner production – Erasmus University in the Netherlands conducted a study in 1992 which concluded that 70% of current waste can be prevented. If this is not happening, it is due to lack of public pressure and absence of agency staff. Andhra Pradesh SPCB has a Cleaner Production Cell to make this effective. MoEF should bring all these initiatives for clean and cleaner production within the country into an effective network, with clear targets for execution. Investing in clean technology is a far sounder investment for the future than investing in landfills.

Thus the HPC has assembled very relevant information which should serve to guide authorities, industries and people on these issues.

1.4.2 The Supreme Court order dated 14.10.2003

The Supreme Court order dated 14.10.2003 in Writ Petition No.657/1995 is based on the HPC report and it clearly prescribes:

1. Efforts are required to minimise hazardous waste in India.

2. The key objectives of the Basel Convention must be noted, which are:

- Minimise the generation of hazardous waste in terms of quantity and its hazardousness;
- Dispose of the hazardous waste as close to the source of generation as possible; and
- Reduce the transboundary movement of hazardous waste.

(The Basel Convention was signed by India on 15 March 1990, and ratified by it on 24 June 1992. India is therefore committed to the above objectives.)

The Supreme Court agreed with other conclusions arrived at by the HPC, namely:

1. That the MoEF made no concerted or consistent efforts of a promotional, educational and co-ordinating nature and it is necessary that henceforth, this should not be lacking on the part of the Ministry.

2. Eighty-nine sites were identified out of which 30 are notified. Out of 30, 11 common landfills are ready and operational (2 in Maharashtra, 1 in Andhra Pradesh and 8 in Gujarat). (This, in other words, implies that the proposals regarding 59 sites are not dealt with seriously, and the majority of the notified sites, i.e., 19, are not yet operational. Even the sites that are in operation are not all in accordance with the criteria set out in the approved manual.)

3. Rule 21 of the 2003 amendment to the Hazardous Waste (M & H) Rules, 1989, in respect of environmentally sound technologies and standards for refining or recycling, should be implemented.

4. SPCBs are not making efforts to inspect facilities and to bring pressure on the units to bring the handling of hazardous wastes in line with their granted authorisations (except in a few cases like Andhra Pradesh and Gujarat). About 80% of the country's waste is generated by the States of Maharashtra, Tamil Nadu, Andhra Pradesh and Gujarat.

5. The Supreme Court set out an Action Plan with 29 activities prescribed: for example, amend the rules, issue closure directions, update inventories, empower CPCB for cross checking inventories, strengthen institutions like the MoEF, CPCB, SPCBs, PCC and research wings, etc. A Monitoring Committee was constituted with

Dr G. Thyagarajan, Senior Secretary, COSTED, Chennai as Chairman and seven others.

When all these directions in the order are fully implemented, industry will find the proposal of cleaner production more attractive, which is also the suggestion of the Menon Committee.

1.5 Environmental Audit

1.5.1 The Environmental Audit Statement

Effective waste minimisation can commence provided a waste audit is first carried out. This is seldom done by industries. Instead we conduct a statutory Environmental Audit (EA) also known as the Environmental Statement (ES). This is different from a waste audit. EA/ES is aimed at checking how far the statutes are complied with and how much work is still remaining. A waste audit, when properly undertaken, helps to assess the performance efficiency of waste reduction efforts. The EA/ES, which has to be submitted under Rule 15, has devoted three parts out of seven to solid waste minimisation, and in that way bridges both the aspects, if taken seriously.

EA/ES can indeed serve as the first step in opening the door to waste examination, taking an overview of inputs, outputs and released pollutants including their reuse. This will have to be done for each unit process and unit operation of the factory.

The more questions we ask, the more significant are the results obtained in the EA/ ES. These aspects are now discussed part by part as per the prescribed proforma:

Part B: Water consumption audit:

1. The actual water consumption figures shall not exceed the consented water input figures, total as well as utility-wise, that is, domestic, process, cooling, etc.

2. The actual water consumption figures shall tally with the twelve monthly returns submitted by the industry to the SPCB under the Water (P & CP) Cess Act, 1977.

3. The actual water consumption figures shall be within the limits sanctioned for certain categories of industries under the Water (P & CP) Cess Act, 1977, (or Charter 2003, whichever is lower).

4. Has permission to tap ground water been obtained? If yes, for what quantity? Does this well appear on the 7/12 Extract of the Revenue Department record?

5. Is the water source purified before supplying it to process and to workers? Are the water works properly maintained and are monitoring results satisfactory?

6. Is the wastewater arising out of water works, like settling tank sludge or rapid sand filter back-wash waters, treated before being released?

7. Is any rain-water harvesting measure undertaken? Has the quantification been informed to the SPCB? Does the input quantity granted by the SPCB in its consent terms/order include or exclude the quantity so harvested? (Similar scrutiny needs to be made if the industry is using ice or steam from outside.)

8. The domestic water input should be reasonable. For designing city water supply, the government normally takes 140 litres per capita per day as a thumb-rule. This assumes a citizen's requirement for 24 hours, and it also includes water required for public purposes like parks, fire fighting etc. In an industry, the factory worker stays in the factory only for eight hours. If the industry is assuming domestic water use as more than 70 litres per worker per shift, there is a scope for exploring conservation measures.

9. The same applies to water used for boiler blow-down, cooling, purging water and some other treated water sub-streams.

10. The Water (P & CP) Cess Act, 1977, is based on a scheme which calculates the incoming water used, with the outgoing quality of the corresponding wastewater. For making such a break-up reliable, fixing of water-flow meters at many places will be necessary. How many meters the industry has provided in their premises and how many of them are working is a relevant issue.

11. If the industry produces only one item, the water attributable can easily be worked out. However, if there are a number of products, for example, pharmaceutical formulations, or a number of sizes in the same product, for example, pipe-making in different diameters or lengths, deeper study is required.

Where all the above aspects have been seriously addressed, the statistics of 'water use per unit of product' can be reliably worked out; and if not, re-working is necessary. In order to bring about water conservation, some engineering is required and for that some funds will have to be earmarked. The EA expects that this commitment will be made.

Part B: Raw materials conservation audit

1. The actual raw material consumption figures should not exceed the consent-application input figures, total as well as utility-wise; for example, reactants, reagents, solvents, work-up, chemicals, catalysts, etc.

2. The actual raw material consumption figures shall tally with the twelve monthly register of the main store of the industry and not the shop level calculations.

3. The actual raw material consumption figures, especially for hazardous chemicals, shall be within the figures submitted in the application for authorisation for certain categories of industries under the Hazardous Waste (Management & Handling) Rules, 1989 and Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989.

4. Have commensurate permissions been obtained from other departments like the Factory Inspectorate, the explosives department, insurance company, etc.? If yes, for what period? Are all special conditions mentioned therein being followed as per the record?

5. Are alternative sources of raw materials being explored, especially in cases of hazardous chemicals? Is the incoming raw material thoroughly analysed in the laboratory before accepting and using it in the factory process? Are the laboratory instruments sophisticated enough, are they maintained in order and are the monitoring results documented?

6. Are spills, leaks, overflows, fugitives, contaminated soil from tank-farm areas and other wastes arising out of unloading, transshipping, storing, unloading, carting internally and stock-taking collected, measured and treated before being released into the environment?

7. Is any reclamation or harvesting being undertaken? Is the quantitative data submitted to the SPCB? Does the input quantity submitted in the application forms for grant of consent and authorisation by the SPCB, include or exclude the quantity so recycled?

8. The raw material input should be reasonably assessed. For designing a process, some figures are assumed. These may be re-written in a mass balance format. Then based on the actual annual production of the previous year, the quantity of required raw material should be reworked and compared with the figures assumed, to see if there is scope for conservation. The same goes for energy and some other utilities.

9. Measuring, counting, weighing is the basis of materials used. For making such quantifications, an accurate scale – and its frequent calibration – is necessary. This is a matter of relevance. Therefore, a list of corresponding measuring devices written against every environmentally important raw material is to be prepared.

10. If the same raw material item is used in two products simultaneously, how would the total purchases of the year be divided between these two requirements? Careful daily documentation will help.

Where all the above aspects have been seriously addressed, the statistics of 'particular raw material use per unit of product' can be reliably worked out; and if not, re-working is necessary. In order to bring about raw material conservation, some engineering is required and for that some funds will have to be earmarked. The EA expects that this commitment will be made.

Part C: Pollution audit, water

1. It is not enough to attach a few analysis results as indicative of a pollution audit. What is needed is to know the pollution load generated and released into the environment, over the previous one year. Some pollution is permitted by SPCB and the EA desires to know whether and how far the industry is within the limits prescribed. The parameters may be separately prescribed for treated domestic sewage, cooling waters purged, cyanide-bearing stream, other industrial effluents, scrubbing water, etc. The exercise of comparison is to be

done substream-wise, wastewater-wise and parameter-wise. The inferences have to be based on reliable number of samples. There should also be a statistical treatment of the data gathered. Only an arithmetical mean, with a range of maximum and minimum, does not give a correct picture. Standard deviation, ninety percentile will give an idea about the tendency of drift from the centre. If this is not done, re-working is necessary.

2. The sampling and monitoring need to be convincing. This exercise is normally undertaken by the industry, SPCB/CPCB team, third party laboratory appointed by the industry but approved by the SPCB/CPCB/MoEF/state government environment department, or maybe by an outsider like an NGO, university or environment brigade member. If the industry draws a sample simultaneously when the others are drawing it, or if the same sample is divided into two equal representative parts, a desired basis for comparison is obtained. Analysis procedure too should tally to get reliable comparison.

3. If the values in any parameter are exceeding the limits on an annual basis, the industry will have to design some upgradation of their ETP, or modify the manufacturing process/equipment.

4. Reduction in toxicity is of utmost importance. The efforts and success in that respect need to be closely examined.

In order to bring about the desired results, some engineering is required, perhaps commencing from segregation, and for that some funds will have to be earmarked. The EA expects that this commitment will be made.

Part C: Pollution audit, air

1. It is not enough to attach a few analysis results of stack emissions or of three stations for ambient air quality (AAQ), as indicators of pollution audit. What is needed is to know the pollution load generated and released into the environment, over the previous one year. Some pollution is permitted by the SPCB, and the audit desires to know whether and how the industry is within the limits presently prescribed. The parameters may be prescribed separately for boiler stack, sulphur-burners, incinerator stack, scrubber, process vents, diesel generator set stack as well as AAQ, etc. The exercise of comparison is to be done sub-stream wise and parameter wise. The

inference has to be based on a reliable number of samples. There should also be a statistical treatment of the data gathered. Only an arithmetical mean, with a range of maximum and minimum, does not give a correct picture. Standard deviation, ninety percentile will give an idea about the tendency of drift from centre. If this is not given, a re-working is necessary.

2. The sampling and monitoring must be convincing. This is normally undertaken by the industry, SPCB/CPCB team, third party laboratory appointed by the industry but approved by the SPCB/CPCB/MoEF/State Government Environment Department. If the industry draws a sample simultaneously when others are drawing theirs, it is a desired basis for comparison. Analysis procedure too should tally, to get reliable comparison.

3. If the values in any parameter are exceeding the limits on annual basis, the industry will have to design some upgradation of its emission control equipment (ECE) or make necessary modifications in the manufacturing process/equipment.

4. Reduction in toxicity is of utmost importance. Efforts made and success in that respect need to be closely monitored.

In order to bring the pollution levels within limits, some engineering will have to be done, commencing with fugitive emission control, and for that some funds will have to be earmarked. The EA expects that this commitment will be made.

Parts D, E & F: Solid waste management

1. The statutory Environmental Audit Rules have given great importance to this subject, devoting three full parts to it. This is rightly done because polluted water may get diluted as it flows away, polluted air may disperse as it blows away; but the solids remain at the same place, posing a threat and a danger almost perpetually. Furthermore, solids are capable of increasing water pollution through leachates and air pollution through volatilisation.

2. Parts D, E and F cover both hazardous solid waste and other solid wastes. The definition of hazardous solid waste includes the substances listed in the three schedules appended to the Rules and which show the enlisted properties. If hazardous waste is mixed with some other wastes/substances, in the hope that its concentration will

be thereby reduced, the entire increased mass becomes a hazardous waste, thereby increasing responsibilities.

3. The quantification of hazardous waste generated from production process cannot be one single number of annual tonnage. The figures are required category-wise, schedule-wise. These can be given only when there is good documentation. Part D also expects information on the hazardous solid waste generated from the pollution control facility, as separation of solids from liquid or gas. This can be given only when there is good documentation at ETP and ECE. The total figure should tally with the manifest (gate-pass), as well as with returns prescribed under the rules (form 4). Here the product-wise split-up of waste is not asked. However, it is desirable to show whether the waste in the present year is reduced when compared with the previous year's.

4. The re-utilisation of solid waste is to be entered annually. This should be on a continual improvement basis. Thus, this part of the environmental audit cannot be satisfactorily completed unless a waste audit is made. The right strategy supported by proper technology will have to be explored, which may be peculiar or specific to different categories of solid waste.

5. Reduction in toxicity is of utmost importance. Efforts made and success in that respect need to be closely examined.

6. To help in the selection of strategy and technology, vendors and the laboratory need to be consulted. The characterisation forms a basis not only for designing the same, but also to know how the outcome can be re-utilised. The priority ranking too depends on this.

7. Attaching a few analysis reports will not be of much use as any half-hearted attempt will be insufficient to put at stake the costly recovery equipment. Characterisation, treatability, laboratory/bench-scale/pilot trials with subsequent scaling up deserve to be attended to before-hand, and so presented in these three Parts D, E and F.

Part G: Impact on the environment

1. This part has two aspects: impact on the outside environment due to the industry's activity of creating pollution; impact on the inside working due to the industry's efforts to prevent pollution. The former needs an EIA study and the latter needs a cost-accountant.

2. Impact is to be assessed on surface water, ground water, storm water, ambient air, property in the vicinity, aesthetics like odour, colour, chemical accidents, bio-diversity and public acceptance of nuisance. Detailed, periodical sampling and analysis is to be designed and documented, including statistical treatment of figures.

3. The audit insists that the consumption of water and raw materials should be reduced and solid waste be reutilised over and over again, further reducing the need for fresh input of materials. Only saying that this is done is not adequate unless quantified. If such saving results in lowering the cost of production, then indeed it is a sure sign of success.

4. The environmental impact may be beneficial, adverse or neutral. It may be beneficial in one area, but adverse in another. Some impacts may be reversible. If we have, e.g., 5 products and 6 environmental attributes to judge impact, then there emerges a matrix of 5 x 6 or 30, and a summation of all this will give us the impact in one word. This needs systematic paper work.

5. The effect on the cost of the product may be positive, adverse or neutral. It may be beneficial in one product where recycling and conservation could be done, but adverse in other one. If we have, for example, 5 products and 7 cost-attributes (like capital cost, operating cost, training cost, waste disposal cost, insurance cost, etc.) to judge effects on cost, then there emerges a matrix of say 5 x 7 or 35, and a summation of all this will give us the impact in one word. This too needs systematic paper work.

If this is so done, the industry has done a correct statutory environmental audit.

Part H: Investment audit

1. This part expects a commitment from the industry for abatement of pollution and protection of environment. Any expenditure incurred for improving the production, resulting is less waste, and any waste treatment either for re-utilisation or for safe entry in environment, is reflected in this part.

2. Any modifications in unloading, measuring, ware-housing, substituting raw materials, instrumentation, micro-processors, production process rescheduling, equipment modernisation, fitting state-

of-art recycling gadgets, upgrading ETP-ECE-incinerator, greening drive, etc., is incorporated in this part, with a funding commitment.

Part I: Voluntary efforts

Part I provides a platform to the industry to project any other relevant information. Matters of interest may be as diverse as tree plantation and survival, noise pollution mitigation efforts, participation in the Public Liability Insurance scheme, progress in obtaining the Eco-Mark, mock drill of on-site emergency plans, having Right-to-Know seminars for the public in the neighbourhood, risk analysis, arranging training programmes or participating in training programmes by others, developing a library, strengthening the laboratory, preparing health records and energy audit controlling VOCs, ODS, PCBs, asbestos survey, water harvesting and similar matters.

Industry should understand that EA is designed not for fault-finding or blame-fixing, but for rectification of past faults and avoiding such faults in future. SPCBs must inculcate this honest approach in the environmental audits prepared by the industries, by a simple assurance that this is a joint exercise and not meant as a basis for prosecution or setting Sections 33A/31A or Section 5 in motion for intended closure.

1.5.2 Waste audit

Quantification of all items should be done as shown in table 5.

Table 5: Waste quantification

Quantity Q of	Denote	Quantity Q of	Denote
Product	A	Total waste	D
Raw material	B	Recycled waste	E
Aid chemicals	C	Disposal waste	F
		Energy	G

A waste audit can be visualised as shown in figure 1.1 below.

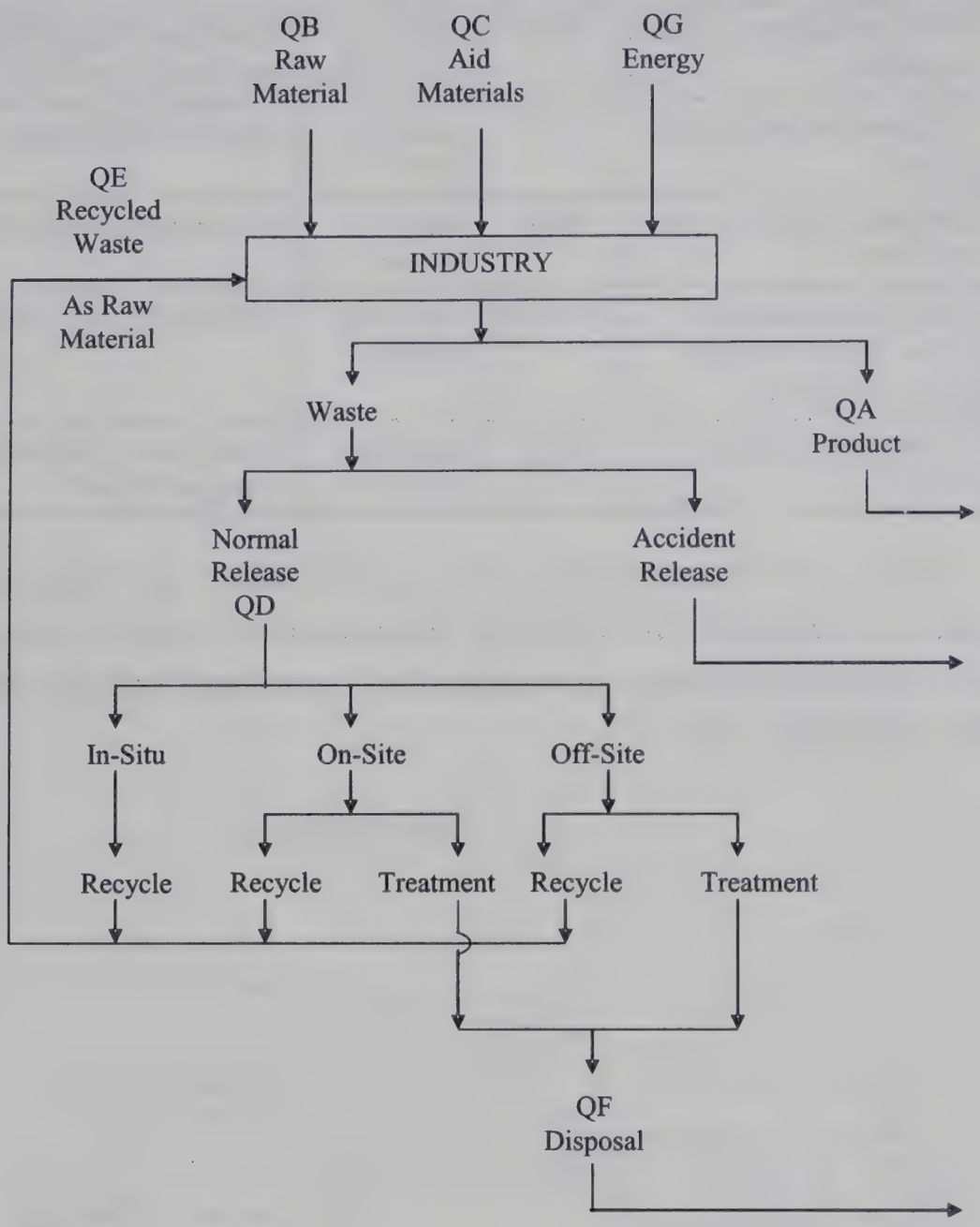


Fig 1.1 : Materials' fate in the statutory environmental statement/waste audit

Indicator ratios can now be worked out as in tabie 6 below:

Table 6: Waste indicator ratios

#	Ratio of	Denote	Signifi-cance	Inference
1	Waste per product T/T	D/A	Less the better	Process and hardware is yield-efficient
2	Waste per raw mate-rial	D/B	Less the better	Raw material selection is good
3	Waste per sum of raw material and aid chemical	D/(A+B)	Less the better	Both 1 and 2 above

4	Recycled waste per total waste	E/D	More the better	Reclamation done
5	Aid chemicals per raw materials	C/B	Less the better	Purer raw material needs less aid
6	Disposal waste to total waste	F/D	Less the better	Disposal is last option
7	Recycled waste to raw material	E/B	More the better	Reclamation done seriously
8	Recycled waste per sum of raw material and aid chemical	E/(A+B)	More the better	Reclamation done correctly
9	Energy per product KW/T	G/A	Less the better	Process and hardware is energy-efficient

If these ratios are worked out continuously, a comparison will tell us as to whether the working can potentially satisfy the requirements of the waste audit, environmental statement and the directions of the Supreme Court.

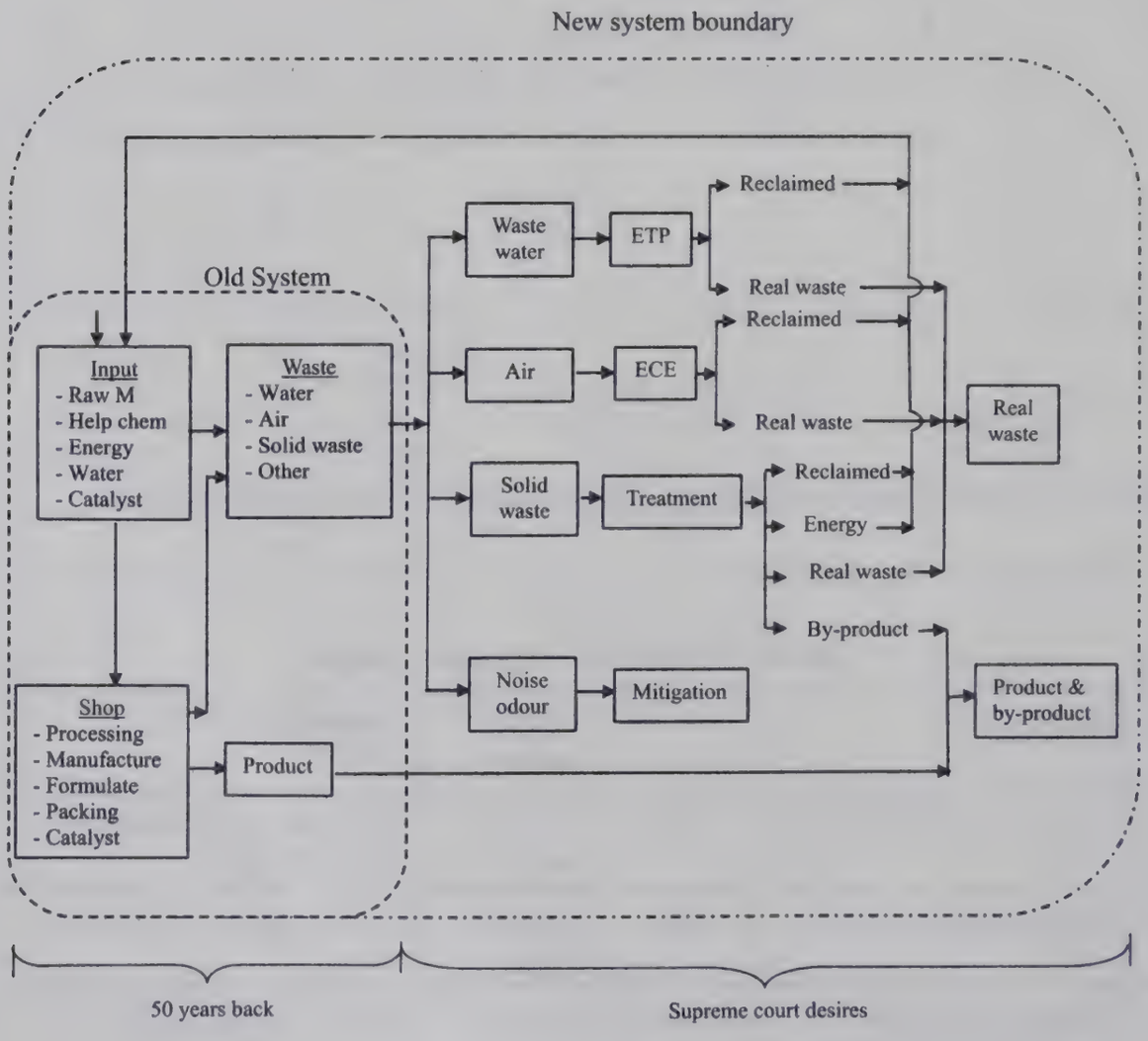


Fig 1.2: Changed strategy of system boundaries

Fifty years ago, the emphasis was not on waste minimisation but today we need to change this mind-set and move towards a new system boundary (figure 1.2), relying upon cleaner production techniques and waste minimisation.

2

WHY WASTE MINIMISATION IS URGENT

2.1 Waste Minimisation is Needed

Waste is not always harmless material. Had it been so, perhaps the community would not have been concerned about it. Industry should, in fact, be bothered about it because it is the owner's money that is coming out in this wasted form. However, industry has not been much concerned in the past because the owner was getting such huge profits from a seller's market that the small off-set of the cost of waste was never a matter of consequence.

2.1.1 Disasters

However, times are now changed. Many ghastly disasters are coming to light. Establishment of new industrial activities, expansions or diversifications are vociferously opposed in public hearings as well as through court proceedings. The following episodes — which have all occurred in the recent past — will show why WM is taking a front seat on pollution control agendas:

1. 1942: At Rocky Mountain, at a military base during World War II, unlined evaporation ponds were constructed for waste disposal and the solid waste buried, as in a land-fill. The ground water got polluted and the cleanup cost was estimated to range between US$210 to US$1,860 million.

2. 1970: For 25 years, hundreds of tonnes of hazardous waste were dumped into an unfinished canal in Niagara Falls area, NY. When the canal was full, it was covered and schools and houses were built on it by the unsuspecting community. In 1970, the residents observed unusual health symptoms. They were required to be evacuated and relocated elsewhere.

3. 1974: At Flixborough, UK, in a nylon-6 manufacturing plant, fire broke out at a storage of cyclohexane, resulting in the deaths of 28 people and injuries to another 100 persons.

4. 1976: At Seveso, Italy, in a herbicide plant, dioxin was released entirely due to human failure.

5. 1978: At Chester Pa, USA, a waste facility existed containing 10,000 containers with unknown chemicals. As time elapsed they got rusted and started oozing, resulting in bursts of flames from time to time. A cleanup operation was started and cost US$2 million.

6. 1980: Local citizens noticed fumes coming out from the Seymour Recycling Co., in which 60,000 barrels of wastes were stored. The EPA was able to prevent the possible danger of pollution entering into the river. This operation involved an expenditure of US$800,000.

7. 1980: Fire broke at an inactive waste treatment facility in Elizabeth, New Jersey, USA. The site had 20,000 leaking and corroded drums of pesticides, explosives, radioactive and acid wastes. Significant quantities of water used in the fire fighting operations entered the river, with resultant adverse impacts.

8. 1984: The Union Carbide pesticide plant at Bhopal killed over 2000 people and affected over 200,000. The fire fighting equipment could rise to 100 feet maximum, but the gas vent stack was 120 feet high, which rendered the fire fighting operations entirely useless.

9. 1992: At Castleford, UK, in a plant producing mono-nitro-toluene, sludge developed resulting in five deaths. Compensation damages were to the extent of £400,000.

There are many such occurrences of unforeseen acts and events (see also similar instances recorded in Chapter 7) that are coming to light every day, clearly underlining the need for those involved in such operations to take responsible care.

Transportation of hazardous wastes is itself often hazardous. It is estimated that in Maharashtra state alone around two million tonnes are transported per annum by rail or highway routes. This can result in accidental spillage or leakages en route resulting in adverse impacts on peoples' health and property.

2.1.2 Common facility – Not a solution

Collective end-of-pipe treatment and disposal facilities for wastes are here to stay for a while, but one needs to appreciate that they are not without their potential demerits such as:

- There are too many member industries, with too many industrial processes, each having their peculiar industrial wastes. Knowing each is an uphill task, knowing the mix more so. It becomes difficult to plan the handling and management of mixed wastes.
- Every member industry already has a possibility of diverse production, and the combination varies every time depending on seasonal demands.
- If the majority of the members switch from, for example, organic to inorganic products, then the landfill will soon fill up and the incinerator may be idle or vice versa.

Moreover, the general public is reluctant to allow such facilities in the vicinity of their homes, fearing that even abandoned landfills may later on generate leachates or gases. NIMBY ('Not In My Back Yard') and LULU ('Locally Unaccepted Land Use') reflect the new misgivings. Each time a landfill site meets with such failure, the word spreads, and there is greater opposition to new sites. In the USA, a survey published in 1987 indicated that out of a total of 4,826 facilities, 2,484 i.e. 51.47% required corrective action. MPCB has six sites under its jurisdiction, and it is found that the majority of them require improvement.

All this only means that a number of episodes, unforeseen acts, events and accidents either on-site, in transit or off-site can happen involving hazardous wastes and that precautions are necessary. In any case criminal liability cannot be transferred, and hence it is necessary that every industrial occupier plans to minimise his waste, with the ultimate aim of zero pollution or zero waste.

2.1.3 Contemporary regulations

It is useful to examine how other industrialised countries have dealt with such problems.

In the USA, the Solid Waste Disposal Act (SWDA) was promulgated in 1965. It was subsequently amended and in 1976 renamed the 'Resource Conservation and Recovery Act' (RCRA). The Act defines hazardous waste as:

'A solid waste – or a combination of solid wastes – which, because of its amount, concentration, or physical or infectious characteristics, may pose a hazard to human health or environment when improperly stored, treated, transported or disposed of.'

The RCRA was itself amended twice. The Hazardous Solid Waste Act (HSWA) of 1984 covered both hazardous and other solid wastes. It added many new requirements like (a) use of innovative and emerging technologies to improve the treatment of hazardous waste and (b) need for changing raw materials or modifying the production process so as to prevent or reduce generation of hazardous waste.

The law was further sharpened with the Comprehensive Environmental Response, Compensation and Liability Act, 1980 (CERCLA or Superfund) which provides for a tax to be levied on chemical industries to clean the hazardous waste sites by treatment or by removing contaminated soils. Under this law, potential responsible parties (PRPs), which include present and past owners of industries or operators, generators and transporters of corresponding hazardous waste, are investigated.

The Land Ban Regulation, 1989, restricted numerous wastes from land disposal, which traditionally was the least expensive option, and a short-cut taken for granted. The Land Ban Regulation was implemented in steps. Step 1 controlled spent solvents and dioxins, step 2 included liquid wastes containing certain metals, for example, free cyanide, PCBs, corrosives with pH <2.0, as well as non-liquid hazardous waste with halogenated organic compounds. Step 3 concluded in 1992 and specifically enlisted 537 scheduled chemicals.

In 1990, a Toxicity Characteristic Leaching Procedure (TCLP) was given legal status, which required more stringent laboratory procedures to be followed. In 1990, all these rules were formally codified to form the Code of Federal Regulations (CFR), a massive

510 pages document. Soon it became evident that the government agencies would not hesitate to hold corporate officers, rather than corporations, liable for environmental pollution. The threats of personal fines and terms of imprisonment held out to the industry's managers are now believed to be far more powerful disincentives to environmental noncompliance than corporate fines. The Pollution Prevention Act, 1990, established a hazardous waste management hierarchy as the national policy. It declared that pollution should be prevented or reduced at the source itself wherever feasible, while the pollution that cannot be prevented should be recycled in an environmentally safe manner. In the absence of feasible prevention or recycling opportunities, pollution must be treated. Disposal or release into the environment should be permitted only as a last recourse.

In the USA, the extent of civil and criminal penalties is prescribed in Federal and/or State laws. State civil penalties may result in fines as high as US$50,000 per day per violation. State criminal penalties may result in imprisonment upto eight years and/or fines of US$500,000 in Colorado and 15 years and/or US$250,000 in Texas. Cases of enforcement actions can be seen in the following examples:

- An Indiana court fined Bethlehem Steel Corporation, US$6 million for 'long standing and willful violation' of RCRA in 1993.
- A person dumping 16 drums (55 gallons) in a creek in Mississippi was sentenced to prison for 3½ years without parole in 1990.
- In 1989, three employees were sentenced to three years probation and 1000 hours of community service, for storing hazardous waste in an unscientific way.

The first Earth Day on April 22, 1970 sparked America's modern environmental movement. From NIMBY (not in my back yard), it soon became NIABY (not in anybody's back yard). Eventually, it became LULU (locally unwanted land use).

In India too, statutes are progressively becoming more stringent. The Hazardous Wastes Rules, 1989 have been amended twice already.

The soaring costs of hazardous waste management, stricter environmental standards, a tougher government enforcement programme, high potential liability for improperly managed hazardous waste, public rejection of sites and NGO activities all result in ever-increasing costs. In the USA, the cost of landfills increased from US$64 per unit in 1983 to US$186 in 1987 and for incineration it increased from US$1.50–3.10 to US$2.36–5.02 in the same period. Now land ban regulations make treatment compulsory and costly. Further, individual problems faced by operating agencies of TSDFs make them to err on safer side by charging more. If some member industries stop sending material, the high overheads have to be borne by a smaller number of industries. Statistics of the year 2004 show that although full capacity of 1,30,000 tonnes per year was available collectively in Maharashtra state's TSDF facilities, they received only around 88,818 tonnes. Further the daily average figure fluctuates widely. Nevertheless, it is certain that hazardous waste quantities are steadily increasing and that great risk to the environment still exists.

As the TCLP brought twelve more industries like petroleum refinery, pulp and paper, synthetic fibre, organic chemicals and even petroleum marketers under legal purview, interstate transfers in the USA are becoming more costly as each state levies import fees. Alabama, for example, increased its fees from US$22 to US$112. As the waste passes through many states, they too charge en route fees. Thus, the cost can be as high as US$2,500 if the waste passes through seven to ten states. In India, interstate shifting is far less in volume at present.

Thus the waste disposal cost is becoming so high that it leaves only four options before the industry, namely: 1) minimise waste; 2) close the industry; 3) dump stealthily or at night; or, 4) get false certificates declaring the waste as 'non-hazardous'. Awareness is shutting the door for options 3 and 4, while demand for goods makes option 2 inappropriate. Option 1 is therefore the only solution left.

2.2 Future Scenarios

While WM or conservation of resources is not made strictly compulsory as yet in India, there is every likelihood of this happening in the near future. Consider the following possibilities:

1. Increasing number of episodes, as narrated above, are recurring all over the globe, resulting in regulatory programmes becoming more aggressive. Sooner rather than later, industry will be compelled to voluntarily prepare waste reduction programmes. SPCBs already have Section 5 ('power to give directions') of the Environment (Protection) Act, 1986 to use against industry.

2. The MSIHC (Manufacture, Storage and Import of Hazardous Chemical) Rules, 1989, promulgated under the Environment (Protection) Act, 1986, have provisions on hazardous chemicals, namely, to take steps to prevent major accidents, to notify accidents, to notify sites, to prepare safety audits, to prepare emergency plans, to disclose information, and matters attendant. These are presently not seriously enforced, but are likely to be tightened tomorrow. The MSIHC Rules had listed 434 chemicals in 1989 as hazardous. The list was expanded in 2000, to include 684 chemicals. The toxicity definitions are also changed. The legislative trend is thus towards stringency.

3. Legal definitions are being revised to bring many more wastes into the control net. In 1989, hazardous waste at category no. 16 was merely defined as 'Acid/Alkaline slurry'. Nothing was stated as regards hazard characteristics. In the 2003 amendment, 'corrosive' nature was defined by its pH range. Today the pH range is 'less than 2 and more than 12', which means that material between a pH range of 2 and 12 is non-corrosive. If this non-corrosive range is shortened even by 0.5, say as 'less than 2.5 and more than 12' or 'less than 2 and more than 11.5', large quantities of material would move from nonhazardous to hazardous category. Further, in 1989, only 18 categories were listed in a single schedule but the amended Rules 2003 list three schedules with 124 items in schedule 1 and 78 in schedule 2. The Rules 2003 also incorporate a list of 13 hazard characteristics like ecotoxicity, infectiousness, oxidising nature, etc, which did not exist in the 1989 Rules.

4. The District Collectors have a tool known as the 'environment brigade' created by virtue of the Government of India Notification dated 17.11.1992, to keep an eye on environmental protection, and there is a move to have such assessors on each assignment.

5. On the one hand there are growing levels of pollution, diminishing nature's capacity to absorb this pollution; dwindling rains. On the other, the affected public is showing lesser tolerance levels, giving rise to a number of public interest litigations (PILs), resulting in greater reason for industry to work for environmental protection and damage control. All these are probable compulsions that industry must take into account right now.

2.3 Stringent Permit Writing

PILs not only bring pressure on the erring industry, but also on the authorities in the area. At least two State Boards have proposed to strictly enforce the existing provisions of the Acts and to procure better compliance from their industries. Consent and authorisation conditions have become more stringent, as can be seen from the following:

1. The formats of applications for consent/authorisation have been revised to demand more detailed information for scrutiny, including aspects like source of water, use of groundwater, water restrictions, storm-water treatment, production restrictions (quantity and season), fuel rationing, vents treated as stack, commitment for waste strength reduction, special measures such as voluntary proposal for hazardous air pollutants, VOCs, asbestos survey, PCBs, raw material review, inventory control, history of chemical accidents in last five years, etc.

2. Pre-hearing is given to industry and commitments obtained in writing along with a bond for good behaviour like bank guarantees.

3. The consent and authorisation conditions are becoming more stringent due to joint inspections along with other departments like the Factory Inspectorate, the Ground Water Survey Agency (GSDA), the district health officer (DHO), the district revenue officer (collectorate), etc. The statutes aim at minimising the threat to human health and environment. For example, if we are converting

chlorine gas or HCl fumes into hydrochloric acid by scrubbing, the same threat continues though the media used is different. There will be restrictions on such escape routes, nor will dilution be allowed to replace toxicity reduction. Waste minimisation will be either no generation of waste at all or its recovery and reuse.

4. The statutory annual Environmental Statement which presently requires industry to lower water consumption, raw material consumption, and pollution, may soon include lowering the toxicity levels also each year.

5. The SPCBs can include the representatives of local bodies as one category of membership. They will drive home the point that the municipal councils and corporations too should take pollution prevention and control seriously. Enforcement will thus become more stringent, and SPCBs may need to deploy special internal task force.

6. Administrative reforms like strengthening the Boards by assigning the supervising work to outside agencies, academicians or NGOs are underway.

7. SPCBs can take stock of the situation periodically and even revoke the consent order midway.

2.4 Lulu/Nimby – Public non-acceptability

The awakening of the community to the hazardous nature of some of the waste generated by industry has added another dimension to the urgent need for WM. In order to establish certain classes of scheduled industries or activities or for their expansion or for selecting a site for hazardous waste treatment/disposal, the project proponent (PP) has to approach the Ministry of Environment and Forests (MoEF), New Delhi, with two pre-requisites: one, a satisfactory public hearing, and two, an Environmental Impact Assessment (EIA) study.

It will be worthwhile to know something about these two aspects.

2.4.1 Public hearings

People have a peculiar psychology. We love the industrial sector because it gives us products for our daily needs and luxury items

too, offers services to make our life comfortable, provides job opportunities aplenty. The press gets advertisements, the local bodies get octroi and the Government can levy taxes. However, when it comes to pollutants, noise, bad odour or hazards, no one wants the waste and consequences of waste. (In this respect, perhaps all of us are like the family members of Valmiki, the mythological poet-guru, who wanted the money – but not the sin – gained from looting the people.)

'Public,' in the present context, refers to the people concerned with the consequences of industrial pollution. They generally act in the following manner: they are confronted by an issue (for example, the selection of the site). They are divided in their ideas as to how to meet the issue (i.e., whether to accept, decline or sit on the fence at the moment).

To begin with, the first party (public) generally will have two divisions, one in favour of permitting the site and another for rejecting the proposal. Component A is under the fear of threat to property value, public health, safety and environment, with NIMBY and LULU at the back of the mind. However, there is also a component B, who see in the development much needed jobs, tax base, economic growth, nearby shopping, new buses, new fire/bank/telephone services, school and medical facilities. In the course of time, either both the groups come to one conclusion; or if opposing groups adopt dogmatic and sectarian positions, public discussion comes to a standstill.

As in any other meeting, the opinion of a minority but vocal group may exert a much greater influence in shaping the collective opinion. This may be beneficial to environment and safety, or may be otherwise.

If these two opposing groups are to be harmonised, the presence of a neutral catalyst (third party) is necessary. This role of a disinterested, neutral catalyst is supposed to be played by the District Collector or Deputy Commissioner with the help of an impartial panel. This pivotal role played by 'neutrals' brings uncommitted/undecided/'sitting on the fence' people to either one of the two sides. This underlines the fact that the panel has the moral responsibility of remaining neutral so as to guide the people.

It is often seen that one interest group vents a strong fear of ill-effects on health, or danger to property, whether based on science or on emotions. To counter this, the industry (second party) tries to re-assure the people with promises like 'we undertake', 'we guarantee', 'state-of-art process', 'fool-proof, fail-safe technology', 'promise to stop production anytime,' etc., and thereby make the fear raised appear to be a bogey or just plain misinformation. If there is no third neutral party, or there is one such, but neither of the two opposing parties has faith in its neutrality, then a dilemma arises. However, if the third party honestly hammers out a via media of a sustainable nature, the participants can come together. An experienced administrative officer must know how the public opinion can be made rational, and he can help the groups arrive at a decision (though it may not necessarily be the logical or correct one).

The quality of the public's decision depends on the quality of the discussions between all the three parties. It depends on facts, effective communication and flexibility on all sides. On the other hand, it can be marred by propaganda, hypocrisy, tall talks, deliberate misinformation, smokescreen, scapegoats, inappropriate parallels, hearsay, promises, wrong-founded beliefs and ego-problems.

Thus, in public hearings no one starts from zero. Everyone has some opinion and some expectation.

The turning point in the course of a public hearing will occur if the second party (i.e., industry) has a good track record and displays an honest desire to remain in the community and share the fruits of the enterprise beneficially with people and if at the same time, the third party (the government) genuinely undertakes to keep the activities of the proposed industry in check, so that the first party (the public) does not face any mal-effects. Component A of party one will merge with component B of party one and party one as such will merge with party two keeping party three as their common well wisher. If this delicate phase is to be tided over, the industry will have to do some homework to create a good environmental image and the panel will have to be seen as unbiased. A good EIA study is very handy at this juncture, because if this point is lost, the negative attitude of all the parties gets reinforced and stiffens, leading to failure and litigation.

2.4.2 Environment Impact Assessment (EIA) study

An honest and well-written EIA always helps. The write-up should be based on certain principles, follow a procedure and discuss all reasonable alternatives (including optional designs, sizes, process techniques, hardware, compatibility, collaborators, waste minimisation, treatment, mitigation, etc.). The EIA must show how problems encountered at other places can be rectified here or prove that those were ill-founded.

The following points with regard to the EIA may be noted:

- No project has purely beneficial or purely adverse impacts.
- Adverse impacts, with effort, may become reversible.
- The EIA enables the public to make a conscious or rational decision with regard to the benefits expected from a particular industry. This choice often requires trade-offs.

An EIA must cover the following aspects:

- Description of the proposed project.
- Description of the proposed site.
- The specific social, environmental, and economic impact in the influence zone of say 7.5 km radius and also along the entire transport route.
- The relevant 'public concerns', addressing each one separately as cause, mitigation and impact, with different WM measures.

The evaluation report will comprise of:

- The impacts of the proposed activity.
- The adverse effect created by the said activity, which cannot be avoided.
- Alternatives to the proposed activity.
- The relationship between local, short term uses of the environment and long term productivity.
- Any irreversible and irretrievable commitments of resources by proposed activity.

- Views expressed by the public and special comments of the panel, if any.

The EIA must be written in clear and easily understood language and display extreme sensitivity to issues of concern. The writer must consider whether s/he and family would be willing to live near such a project.

The writer of the EIA should consider all the effects, probable and possible, both on health and environment, such as:

- **Effect on people**: Immediate death, chronic illness, chronic disability, minor and temporary illness or emotional illness.
- **Effect on environment**: Ecosystem de-linking, elimination of certain species, reduction of diversity, reduction of species, reduction of biomass and loss of water resources.
- **Social effects**: Disruption of existing communities, negative distributional effects, effects on disadvantaged people or specific types of communities (like tribals), future generation, etc.
- **Economic effects**: Severe damage to man-made structures, severe devaluation of property, loss of productivity of the land, local taxpayers costs towards cleanup, security, and other site maintenance costs.

Until the problems are resolved, it would be dangerous to assume that there are no risks, simply because we have not found a way to measure them. The EIA should therefore err on the safer side. If the reader of the EIA knows that the writer has adopted this line of care, the document will have more credibility. This is the success of an EIA.

2.5 Non-Tariff Trade Barriers

While granting authorisations and consents, SPCBs invariably impose a condition requiring prevention of pollution or minimisation of waste. If this is not complied with, ISO 14001 certification will be difficult to get. Many export orders specify that the parent company as well as the suppliers of raw materials shall have ISO certification. Trade preferences may be lost if this is not available. Managers of

industry are therefore engaged in WM to ensure that the industry is short-listed at the appropriate time.

ISO certification is taking a front row. This subject, which was uncared for in the late 1960s and early 1970s, has moved to the Board of Directors' room in twenty years and the complexity of the subject has also increased. The subject is no more limited to emissions and discharges alone, but covers the entire gamut of business activities and processes. There is deeper thought now behind every word which we previously used quite loosely (see table 1):

Table 1: Old words, added meanings

Word	Meaning
Design	Design for environment and health
Manufacturing	Resource conservation, waste reduction, legislative compliance
Accounting and reporting	Environmental accounting and reporting, GRI guidelines
Logistics	Greening the supply chain
Marketing	Green marketing
Trade issues	WTO and international trade
Life-cycle issues	Reducing, recycling, reusing, as also manufacturing, repairing, end-of-life issues
Opportunity issues	Image, triple bottom line, green rating, green mutual funds
Business risk issues	Potential liability, compliance, due diligence

For handling this, an holistic approach is necessary. ISO provides for that. International purchasers are looking these aspects.

2.6 Definitions

Waste minimisation is an essential ingredient for any industrial activity, either to avoid trade barriers, or legal action or public wrath or to keep good faith with society. Let us now examine the waste management hierarchy. It can be set out in descending order as follows:

1. Source reduction – The reactor itself is modified so that less waste is created, *ab initio*.

2. In-process recycling – The output of a reactor is sent through a separator and any unreacted feed is sent back to the reactor, to produce the same product in the next batch.

3. On-site recycling – The output of a reactor is sent through a separator and any waste is sent to another reactor (instead of the same reactor) but in the same premises, to produce saleable but different products.

4. Off-site recycling – The output of a reactor is sent through a separator and any waste is sent outside to another reactor, to produce saleable but different products.

5. Waste treatment – Waste from the reactor is treated so that it changes and becomes less hazardous.

6. Secured disposal – Waste from the reactor is sent to a secured landfill with or without prior treatment.

7. Direct release – Waste from a reactor is released directly into the environment.

Source reduction is naturally the first preference. It is an in-plant practice which is aimed at reducing, avoiding or eliminating the generation of waste itself. It can be achieved by efforts like input substitution, technology modification, good housekeeping practices and product reformulation. However, any action taken after generation of waste to reduce its volume or to reduce its toxicity by dilution, thereby increasing the volume, or shifting the pollution to other media or imparting treatment to the waste is not strictly 'source reduction'.

Toxic use reduction too can be considered as source reduction, if any of the following efforts are made:

1. Substitution of input raw materials of lesser toxicity.

2. Reformulation of product in such a way that substances used or product produced and waste generated are of lower toxicity than before.

3. Same achievement but by modernisation process.

4. Better and improved control of operation and maintenance facilities.

5. Changes in production processes or raw materials that avoid, reduce or eliminate the use of toxic or hazardous by-products and that reduce the risk without shifting it elsewhere to other media.

However, steps like incineration, media shifting, off-site or out of process recycling or end of pipe treatment, though they may lower the toxicity and are certainly welcome, strictly cannot be called 'toxic use reduction'.

If there is source reduction, it will give added advantages to the project proponent or industry in the shape of resource conservation, energy conservation, reducing need for end-of-pipe treatment, or need for waste containment.

Pollution prevention (P2) is a term used to denote reduction of use of toxic materials or reduction of environmental health hazards without dilution (or concentration) prior to release, handling, storage, transport, treatment or disposal. This can be achieved by adopting proper changes in (1) technology, (2) materials, (3) process, (4) operating procedures, and (5) in-process, in-line or closed loop recycling. However, the practices applied once the waste is generated or after the waste exits the industry are not P2. If an industry is burning its waste for energy recovery, or shifting its waste away from one environmental medium to another, or away from its own workplace or production shop to another, or sending it for off site recycling, or sending it for any other end of pipe waste management process, including waste exchange or incorporation of waste into by-products, it cannot truly be called P2. Steps like source reduction, in-process recycling are P2, steps like out of process recycling, off site recycling are pollution abatement and steps like waste treatment, secure disposal, and slow release to suit nature's absorption capacity are in the nature of pollution control.

Industry's efforts should be understood in the light of these definitions to achieve the goal of WM, which is the urgent need of the hour.

3

PREPARATORY DRILL FOR WASTE MINIMISATION

3.1 Critical Elements

The various episodes of pollution, spills and leachates that we come across have indeed convinced us that waste must be controlled. However, much more effort is required than made at present. Today, raw wastewater is treated, but after treatment it is still wastewater. Though it is better than what it was earlier, it still cannot be called 'water'. We have introduced control measures for air pollutants from major sources like boilers, but fugitives and vents, as well as diesel generator sets are left unattended. Hazardous waste is dealt with by incineration, sales or secured landfill, both as treatment and disposal. This is, however, akin to an 'out-of-sight, out-of-mind' strategy. In some places, pollutants are merely transferred from one media to another, at others, dilution is seen as the solution to pollution. This, however, cannot work for long. In fact, if hazardous waste is mixed with non-hazardous waste, the entire material becomes hazardous. Thus the only sustainable solution will come with waste minimisation aimed at zero discharge.

Waste generation, due to the burden of its disposal, is costlier than efforts required for waste reclamation. Though this was not apparent to begin with, the people who have undertaken such work have found in the end that there is a substantial saving by reclamation and it also has a reasonably short pay back period. Thus BASF, reduced its residual waste by 640,000 tonnes on annual basis.

Various avenues are available for WM. Some have only marginal cost. Some (where the waste is converted to a by-product) can generate revenue. If we have a limited budget, we can prioritise our

expenditure. If it is not possible to take up all the works simultaneously, at least a good beginning can be made in some areas.

While preparing our WM programme, our aims should be:

- Minimise the quantity of waste.
- Minimise the toxicity of waste.
- Minimise the expenditure on recovery process.
- Minimise the potential risk.
- Maximise saving on raw material cost.
- Maximise saving on waste disposal.

These six considerations in fact can be grouped in two, namely, waste related (first two) and cost related (last four). The matrix then looks like this (table 1):

Table 1: Waste matrix

	Reduction of waste [R]	**Cost for programme [C]**
Small [S]	SR	SC
High [H]	HR	HC

The ideal will be SCHR i.e small cost, high reduction, but some times we shall have to go by HCSR i.e., high cost, small reduction in a specific situation. Cost depends on the efficiency of the gadget that we are employing. Cost also depends on economies of scale. Add-on is always costlier. Further, capital costs and operating costs are generally inversely proportional, and at both the extremes, small decrease in one cost requires large increase in the other cost.

The cost of production has many components, and these can be stated as follows (table 2):

Table 2: Costs of production

Capital	**Operating**	**Accountant heads**
Land and building	Fuel	Depreciation
Utilities	Raw materials	Taxes
Production	Operation and maintenance	Interest
Waste treatment plant	Labour	
	Waste handling	

If one commences with pure raw materials (or better still, with outsourced intermediates), uses modern instrumentation (or better still a micro-processor), then it results in less requirement of utilities, raw material, labour, work-up chemicals and even wastes. Total cost is thus an amalgamation of production direct cost, production indirect cost, waste treatment direct cost, and indirect external cost of peoples' health. If the last component is very high, WM is the only answer.

In the above table, various account heads are given leading to the overall costs. One more should find a place there and that is penalties for waste mismanagement. The Federal Republic of Germany had promulgated a Waste Water Charges Act in 1976. The charges were to be levied by determining 'noxiousness' of the released wastewater. The method of (A) assessment of units and (B) the method of laboratory estimation were both prescribed under the Act.

Table 3: Determining the 'noxiousness' of wastewater

#	Pollutants parameters	Estimate by	Unit of noxiousness	Per
1	Settleable solids containing more than 10% organic matter	2 hour settling	1.0	Cu.m of wastewater
2	Settleable solids containing less than 10% organic matter	2 hour settling	0.1	Cu.m of wastewater
3	Oxidizable substances as COD	Dichromate procedure	2.2	Per 100 kg
4	Mercury and its compounds	Atomic absorption spectrometry	5	Per 100 gm of mercury
5	Cadmium and its compounds	Atomic absorption spectrometry	1	Per 100 gm of cadmium
6	Toxicity for fish (Bio-assay)	Bio-assay with various dilution	0.3 D (*)	Per 1000 cu.m

(*) D represents the dilution factor at which wastewater loses its toxic effect on fish

The charges would be levied annually and the rate kept increasing every year. This example is cited merely to indicate how imposition of penalties may make things difficult for industry.

3.1.1 Uncertainties in the waste reduction programme

The reason why estimating the costs of such programmes is difficult is because the variables are many.

- There is no record of waste generation per unit output.
- Industrial activity and product mix change as per customers' demands.
- The legal definitions change (e.g., the definition of corrosion in India and abroad is different; further, in India the definition of hazardous waste was revised twice in three years).
- Waste volume may reduce but its hazard level may not similarly reduce.
- Dilution may disperse the same amount of waste but larger volume is difficult to handle.
- There are too many industrial unit operations and unit processes in series and change in one disturbs the detailed calculations made earlier for all other units that follow.
- Waste generation and possibility of its reduction are all process-specific; parallels are seldom prone to extrapolation.
- The process technology and products may change widely, especially in pharmaceuticals and pesticides where the demand changes per season or as per acquired immunity.
- Waste consistency is variable: it may be in solid, sludge or slurry form, or as a liquid or air pollutant.

3.1.2 Reactors and reactions

In a chemical industry, the main unit is the reactor. It holds the reactant raw materials and solvents and transforms them within a certain period. Whatever is generated here is in mixed form such as the product, mother liquor and waste. These are to be separated and then taken out separately. For running the reactor, some external utilities are required: the furnace, steam or a cooling jacket, etc. For running the reaction, some internal helping hand is required: for example, catalysts, work up chemicals, product washing water, etc.

As a natural corollary, this creates two types of wastes, namely, process waste and utility waste. Our aim is to minimise these two wastes, which in turn means to minimise the requirements of:

(1) Quantity of input chemicals.

(2) Need for separation and purification.

(3) Utility inputs.

(4) Catalysts and work-up chemicals.

If (1) and (2) above are kept in check, there will automatically be less need of (3), and if (1), (2) and (3) are under check, there will be less need of (4).

Thus the central aspect is the chemical reaction, indicated as (1) above. It takes place in one of the following three ways, or as a combination of these three ways, namely:

1. Raw materials A and B react and create a product as well as waste. Thus:

$A+B \rightarrow$ product + waste

2. Raw materials A and B react and create a product, as well as discarded product or by-product and waste. Thus:

$A+B \rightarrow$ product + by-product + waste

3. Raw materials A and B react and create a product, but impurities in these two raw materials (say x and y) either react among themselves or react with the other raw materials and create many types of waste. Thus:

$(A + x) + (B + y) \rightarrow$ product + Ay +Bx + xy

Which way the reaction will run is important. The essential point is correct design of the reaction and the reactor (which is the work of the chemist and the chemical engineer respectively). The following points may be noted:

1. There are two types of reactions, viz., reversible and irreversible. If one has a choice, it is better to adopt the irreversible option. This is because in a reversible reaction, the raw material may change into a different product as time elapses in the reactor or if conditions change in the reactor like temperature, pressure or mixing.

2. An irreversible reaction namely $A + B \rightarrow$ product + waste is much simpler because this waste can be controlled by selecting a proper feed ratio, adjusting it, keeping it in excess, adding some inert

materials, changing temperature if endothermic, changing pressure if the reaction leads to a decrease in number of moles, and correctly distributing and mixing the material.

3. One way to avoid intermediates and by-products getting converted into waste, is to examine whether one can carry intermediate separations of products as the reaction proceeds. This avoids conversion into wastes.

4. Purer raw materials will avoid subsequent cross reactions and waste. It is preferred either to procure the raw material in pure form or else purification steps should be introduced before charging.

5. Catalyst selection is very important. Heterogeneous rather than homogeneous catalysts are preferred as the latter are difficult to segregate and recycle. Thus better flow distribution, better heat transfer and instrumentation and introducing catalyst 'diluents' helps.

6. A steady state reaction is desired and hence start-up and shutdown losses should be reduced.

If care is taken of one, there is less need of taking care of the other.

3.1.3 Separation

The separation process is very important in the chemical industry as it relates to working capacity, operating costs, and sources of waste. Synthesis precedes separation. Purification precedes or follows (or both) separation. If conversion is incomplete it results in waste, and if separation is incomplete, that too results in waste. A separation process, to begin with, essentially has a mixture of more than one material, which it has to transform into different, distinct, material streams. For achieving this, a separating agent is required. This agent is either in a form of energy or in the form of another set of materials. Where the mixed materials awaiting separation are of different densities (or relatively different volatilities), separation is easily accomplished by mechanical means (i.e., by applying energy in some form). Such examples are filtration, centrifugation, settling, floatation, etc., selection of which depends on the stage of the feed and the product at the time of separation. Common text book separation processes are shown in table 4:

Table 4: Common separation processes

Process	Phases of		Separating agent (E=energy and M=material)
	FEED	PRODUCT	
Flash evaporation	Liquid	Liquid + Vapour	E Pressure reduction
Distillation	Liquid/ Vapour	Liquid + Vapour	E Heat
Stripping	Liquid	Liquid + Vapour	M Stripping vapour
Absorption	Vapour	Liquid + Vapour	M Liquid absorbent
Extraction	Liquid	Liquid-1 + Liquid-2	M Liquid solvent
Crystallization	Liquid	Solid+ Liquid + Vapour	E Heating or cooling
Evaporation	Liquid	Liquid + Vapour	E Heat
Drying	Solid / Liquid	Solid + Vapour	E Heat
Leaching	Solid	Solid + Liquid	M Liquid solvent

In certain applications, a popular way of separation is distillation. Its efficiency is related to the number of plates, column diameter and bubble hole geometry. The ratio of quantity of liquid returned to the column as reflux, to the quantity of top product flow rate, is usually called the reflux ratio. A high ratio reduces the number of plates but increases the column diameter and energy costs.

The following points may be noted with regard to separation processes:

- Combine similar streams to minimise the number of separation units.
- Remove unstable and corrosive material early.
- Separate the compound of highest volume first.
- Make the most difficult separation last.
- Carry out separation of high purity recovery compounds last.
- Use a sequence resulting in the smallest number of products.
- Avoid adding new components to the separation sequence.
- If a mass separating agent is used, recover it the next step.
- Avoid extreme operating conditions.

A process has four components: charging the raw materials and reagents in the reactor, supervising the kinetics in the reactor, separation process in the reactor and discharging the mass. All this is traditionally done by manual control in small scale industries having batch operations and where less hazardous materials, less hazardous processes or less hazardous products are involved. However, now we know that it is impractical, unsafe and unprofitable to run such plants manually. Automatic control is an essential feature of large scale, continuously operated plants. No longer is it sufficient to assume a perpetual steady state. If a reaction becomes unsafe, modern gadgetry can even shut down the plant automatically. Automation helps to maintain product quality, produce rated quantity, avoid break down and attendant risks and most important, control the resultant waste. Further, it generally makes full use of utilities like steam, electricity, cooling water, compressed air and labour, etc., and saves corresponding losses too.

In order to avoid any runaway reaction, proper measuring is required of material flow-rates, temperatures, pressures at various locations, compositions, liquid levels at various storages and consistencies of materials (whether reactants, reagents, intermediates, mother liquor, product, by-products or waste). Some changes are slow while others are abrupt. The measuring element must respond quickly to the changes. A thermocouple directly immersed in a flow responds quicker than one welded to the outside of a pipe and is hence preferred (albeit taking care to observe corrosion). Controlling follows the measuring. Traditionally, the controllers are mechanical devices operated manually or pneumatically*. However, with the advent of analogue electronics followed by digital microprocessors, instrumentation and control is disciplined. Installation of even a small microprocessor will enable handling of as many as 1 to 16 control loops. It is desirable to review what other methods are available if our present measuring methods and devices deserve to be changed, as shown in table 5:

Table 5: Alternative measuring methods and devices

Parameter	Alternative device/method/principle
Flow-rate	Differential pressure devices (Pitot tube, orifice plate, ventury meter/turbine meter/rotameter/hot wire anemometer)
Temperature	Thermistor/thermocouple/resistance thermometer/expansion thermometer/optical pyrometer
Pressure	Manometer/different pressure cells (mechanical or semi-conductor)/Bourdon gauge
Composition	Chromatography/refractive index/density/conductivity/pH/infra-red or ultraviolet absorption
Liquid level	Different pressure/float/weight of vessel

(*Pneumatic valves are still almost universally used. If a compressor is assisting it, look out for its noise and water controls.)

Proper pH is required to be maintained at all the manufacturing stages. It not only assaults the material of construction, but affects the yield. For example, it is reported that when proper pH is maintained, the tar build-up was found to reduce at a distillation column. In another industry, raw material, neutralised before admission, helped in avoiding generation of acid-tars in the reaction.

It is necessary that all these basic requirements be studied and kept in mind, so that improvements can be researched at the production shop.

3.1.4 Outcome of chemical reactions

The chemical industry differs in one essential aspect from other equally technical industrial sectors, which is, the uniqueness of chemical reactions. Transformation of raw materials into downstream products is the result of chemical reactions, which seldom run 100% in one direction. There are invariably traces of unreacted raw materials present in the final reaction mixtures and also the products of side reactions arising from the main reactants. Such by-products, in most cases, are undesired and must be separated from the desired end product. Furthermore, a wide variety of auxiliary chemicals is added to chemical reactions e.g., catalysts, solvents, work-up chemicals, etc., and these too determine the nature of the by-products. Impurities present in any of the raw materials or the auxiliaries can also remain in the final reaction mixture or in the by-product. This outcome of the chemical reaction can be:

- The desired end product.
- A by-product arising from the main reactants.
- A by-product arising from the auxiliary chemicals.
- A by-product arising from the main reactants and the auxiliary chemicals together.
- A by-product arising from the reaction of impurities in the main reactants.
- A by-product arising from the reaction of impurities in the auxiliary chemicals.
- Unchanged main reactants.
- Unchanged auxiliary chemicals.
- Unchanged impurities in the main reactants.
- Unchanged impurities in the auxiliary chemicals.

The CPCB has published a document (HAZWAMS/12/1998-99) titled 'Ready Reckoner: Hazardous Waste Management' in which the 7-digit code of many hazardous wastes has been worked out. The fourth digit of the code tells us whether the waste referred to is recyclable, unrecyclable or doubtful. It covers a large number of wastes, many of which do not fall under the recyclable category. The matter is so complex that it will be an oversimplification to say that on every occasion WM is certainly possible. And, with new techniques being discovered, possible solutions are also emerging.

3.2 First Steps

3.2.1 Waste audit and emission inventory

The first step towards reducing waste and emissions is to perform thorough waste audits and accurate emission inventories. A waste audit (WA) is conducted to characterise the waste streams generated by an industrial plant, while an emission inventory (EI) is performed to quantify the direct release of pollutants into the environment from the particular shop under study. WA and EI are complementary tasks and both are vital to the development of strategies for prevention of pollution.

A waste audit will answer the following queries:

- What waste streams are generated in the shop?
- Are waste streams generated on a regular basis or are they a one-time event?
- Which process or operation generates the waste?
- What is the regulatory status of the waste? Can it be defined as hazardous waste? What characteristics of the waste are responsible for its regulatory status?
- What are the inputs to the process generating this waste?
- How efficient is the process?
- Are wastes from different sources mixed here?

A waste audit will also provide information concerning the mechanism of waste generation as well as data about the waste stream.

The purpose of an EI is to assess the quantities of pollutants released directly into the environment by the industrial shop. This includes fugitive and secondary emissions, both of which form a significant part of air quality. These are unintentional releases of process fluid from equipment like pumps, valves, flanges, etc., and must also include fugitive escapes (estimation of which is indeed difficult).

The least accurate but least costly method to estimate fugitive emissions is to count all the potential sources of release and apply an average 'emission factor' according to the formula:

$$E = m(voc) \times f(av),$$

Where E is the emission rate of volatile organic compounds (VOC) from a component, m(voc) is the mass fraction of VOC in the stream serviced by the component, and f(av) is the average emission factor.

For synthetic, organic chemical manufacturing industries, f(av) is suggested as in table 6:

Table 6: Average emission factor for organic chemical units

#	Equipment	Serving	f(av) in kg/hour/source
1	Valves	Light liquid	0.00403
		Heavy liquid	0.00023
2	Pump seals	Light liquid	0.0199
		Heavy liquid	0.00862
3	Compressor seals	Hydrocarbon gas	0.228
4	Pressure relief valves	Hydrocarbon gas	0.104
		Liquid	0.0070
5	Flanges and other connections	All	0.00183
6	Sampling connections	All	0.015

An equipment is considered to be leaking if an organic vapour analyser detects VOC concentration greater than 10,000 ppm at the process fluid/air interface. Secondary emissions can come out from exposed wastewaters in ponding, or in ETP units.

For example:

Facts: An uncovered oil-water separator unit in an ETP train has a VOC emission factor of 0.6 kg per cubic meter of wastewater (EPA). The effluent quantity is 7,600 cum per day. The VOCs in effluents are expected to be benzene, toluene, ethylbenzene and xylene and their mass fractions in the VOC portion of the effluents are respectively 0.009, 0.167, 0.130, and 0.694 respectively.

Query: Estimate the emissions of the individual compounds in kg/hr.

Solution:

Estimate the total VOC emissions E, first.

E(Tot) = (0.6 kg per cum of effluent) x (7,600 cum/day effluent quantity)

= 4560 kg/day or

= 190 kg/hr

If Ri is the mass fraction of compound .i, in the VOC portion of the effluent, then the emission fraction Ei,

Ei = Ri x E(Tot)

So for benzene, toluene, ethylbenzene and xylene, emissions are 2.5, 37.5, 25 and 125 kg per hour respectively, totalling to 190 kg/hour.

(Fugitives are of various types – VOCs are only one of them.) While we are on the subject, let us examine how VOCs can be arrested from waste water:

- Add pretreatment of steam stripping or air stripping. Volatile organics so driven off can be recycled and commensurate raw material is conserved.
- Other tools for pretreatment are ion exchange, carbon adsorption, membrane separation and liquid extraction.
- Another method is covering the ETP unit. (Various modes of roof, floating membrane, air-supported structure with venting arrangements are offered by vendors.)

Environment auditors have generally observed that –

1. Determining what wastes are generated is relatively straightforward, but determining why the waste is generated is difficult.

2. Wastewaters are observed to be the dominant component of total waste mass.

3. Direct emissions are at very low rates.

4. Methods available for estimating rates of fugitive emissions provide approximate figures only.

5. Methods available for estimating rates of secondary emissions also produce rough estimates only.

At a large facility with many waste streams, the results of waste audits and emission inventories are used in the process of ranking the streams so that the most important streams can be selected for potential pollution prevention/waste minimisation options.

3.2.2 Preparatory steps

The first step is to study the level of awareness of our shop floor people and then compile the information. The reason is to:

1. Examine whether the staff know enough to handle well the basic utilities and their operations: for example, the boiler, the de-

mineralisation and water-softening plant, the cooling tower, water accounting and water budgeting, refrigeration, vacuum pump, ejector, turbines, mixer selections, uniformity of distribution, weighments, instrumentation, indicators, flow-meters, etc.

2. Examine whether full documentation of process routes is available or make a list of where this is lacking.

3. Examine what solvents are in use, their properties, propriety of particular solvents or possible alternatives and present recovery method.

4. Assemble information on vendors offering not only chemical technologies, but also physical techniques (like ion-exchange, reverse osmosis, dialysis, etc.)

5. Examine catalysts that are used, what substitutes are available in the market, how good is the present recovery for prolonged use and whether an alternative will improve this.

6. Examine whether the treatment system serves only the last limited residuals. A large treatment plant in fact is a discredit if it is a means of absorbing the inefficiency of plant or process.

7. Make a list of the process residues in all the steps. For this, one requires knowledge of chemistry, access to mass spectroscopy and facility to identify species. Library and laboratory may need to be upgraded.

8. Attempt a technical assessment of the industry's present configuration and examine whether it will be beneficial to permit all the reactions in one reactor or to switch to more reactors in series i.e. to do different jobs in separate dedicated reactors. This also applies vice versa, i.e., whether the present series of reactors can be combined profitably and thereby reduce the number of stages.

9. Examine whether some of the raw materials can be procured with short notice and reserved tanks for them can be eliminated or minimised in view of the fact that increase in the number of tanks in the tank farm area results in increases in handling of chemicals and more losses. This is known as the 'just-in-time' (JIT) principle.

10. Examine how many inorganics are used in the process steps, and whether these can be curtailed.

11. Attempt to develop new packing. (In one case, a polymer resin manufacturer dispatched the resins in bags made out of the same resin, so that the buyer chemical industry could feed the entire bag with contents to the reactor. The same is true in case of asbestos fibres. The bag is cut open inside the mixer and both asbestos fibre and shredded bag become raw material.)

12. Examine whether a vacuum pump can be used instead of a stream jet.

13. Train the operators to turn off or shut down idle equipment so as to minimise start-ups and shut-downs by scheduling.

14. Drying design is a common operation. Check whether the design is optimum. For improving this, the following techniques will be useful:

a) Recirculate air.

b) Recirculate air plus minimise in-leakage (improve baffling, seals, air-lock, etc.).

c) Recover organics from the purge stream.

d) Recover energy value from the purge stream.

e) Abate organics from the purge stream.

To begin with, industry operators may find the above tasks overwhelming. However, compared with giant industries most of our shops are quite manageable. Most industries have only a small number of unit operations and unit processes. Going through these minutely should not be a difficult task. At least a preparatory drill can be initiated. It is only by trying different techniques and pursuing different technologies that the goal of WM can be achieved. Compilation of possible sources of information, like universities and vendors, should also be commenced at this stage.

3.2.3 Fugitive loss control

To begin at the beginning, one has to keep a watch on losses. Operators generally lose sight of small losses, but collectively these create substantial problems. The possible sources for arresting losses are tabulated below (table 7):

Table 7: Controlling fugitive losses

Area of	Possible routes of fugitives escaping
Unloading	Time delay in fitting hose Leaking hose or leaking hose connection Draining of fill lines between changing tanks Leaking container, valves, pump packings, piping, or dykes Electrical failure Using of hooks, puncturing the bags
Storage	Tank overflowing Malfunctioning overflow alarms, level controllers Rusted corroded containers or beds Not seen due to unclean house-keeping Not seen due to poor or faulty illumination
Transfer	Holes/apertures in hand carts, trolleys Hooked bags especially at lower level of the heap Old residual chemicals at the bottom of shop floor service tank, too stale and drained to refill afresh
Process	Improperly operated process equipment Improperly maintained process equipment Process/product changed, but existing old equipment pressed in service, thus either too high or too low height of freeboard No dyking for shop floor service tank Sudden equipment/tank draining for cleaning at emergency maintenance Uncollected off-specification raw materials Uncollected off-specification products/by-products Leaking container, valves, pump packings, piping, or dykes Electrical failure
Transporting out	Same as unloading and transfer listed above

If this is included in the training syllabus (or in the check-list), the young operators will be able to prevent wastage at the starting point itself.

While discussing fugitives, liquid storage tanks in our tank-farm or shop too must be considered. The following is a check-list for good operating practices, based on case studies:

- Reduce the volume of vapour space in the tank, i.e., the tanks should not be kept half filled, or the tanks should not be oversized. (It is better to operate 3 full tanks rather than 5-6 half full ones.)
- If it is necessary to add inert, it should be a controlled addition.

- It is desirable to keep the tank at constant temperature. (Where auto-combustion is possible — as in the case of cane molasses — water spray is maintained.)
- Entry of volatile organics from a tank can certainly be reduced, if the vent opens up at a higher pressure.
- If constant level is maintained in tanks, air bubbles and loss are minimised.
- Reduce number of tank-turnovers, as it obviously has a relation to losses.
- Concept of 'floating roof' should be examined as it leaves low or no space for vapours. Can be retrofitted.

Controlling fugitives will have a direct beneficial effect on consumption of raw material, in addition to improving the quality of the environment.

3.2.4 Good operating practices

Many operators believe that modernisation either in process or hardware is the solution to all problems. While this may work out well, it is also worthwhile to try afresh the existing arrangements after making necessary changes in operation, which may give good dividends.

Some experienced suggestions are:

1. Reactor charging:

- Feed solvent by gravity and not by pumping.
- Closed loop vapours should be recycled for pumping operation.
- Charge solids first and then solvents, sequentially.
- Lock the hopper before charging solids.
- Cut open the bags inside the reactor, or as near to it as possible.
- Pass vent through refrigerator. Condense solvents and recycle.
- Use solvent of low vapour pressure.

2. Reactor operation:

- Closed reactor is better or secure lid with good gasket and clamp.
- Improve seals on agitator (better still, replace agitator with jet nozzles).
- Sequentially add the reactants and reagents. For example, do not add all NaOH either at beginning or at the end. Add slowly, continuously, as reaction proceeds.
- Control gas purge rate with automatic flow control devices and not by manual throttling the valve.
- Check reactor mixer and blades.
- Collect excess reactants on the spot.
- Use minimum number of intermediate steps.
- Sampling should be automatic, without the need of having to open the lid off and on.

3. Reactor discharges:

- Discharge lines should be on an incline.
- Reduce reactor temperature before discharge.
- Do not push contents by pressure gas.

4. Reactor cleaning:

- Optimise the sequence.
- Maximise production runs.
- Minimise number of solvent rinses.
- Increase smoothness of vessel walls.
- Use high pressure rotary nozzles to reduce quantity of cleaning solvent.
- Replace volatile chlorinated solvents with low-volatile chlorinated solvents or better still, with non-volatile chlorinated solvents or even better, with non-volatile non-chlorinated solvents, or best with aqueous based detergents.
- Collect final rinse wash for reusing, as first pass at the next cleaning.

- Use plastic beads, wheat starch or sodium bi-carbonate with water.

5. Report:

- Send observation remarks, if any, to the boss immediately.
- Communicate alternatives which can be used, to the boss at the earliest.

3.2.5 Good maintenance practices

Like good operating procedures, good maintenance practices are also important. Many times these are lost sight of because those in charge are too busy with production. At best, corrective maintenance is followed, i.e., merely keeping the machines in running condition. In fact, the concept of preventive or predictive maintenance is far more effective. For this, one needs to first make a list of:

- All plant equipment and locations.
- Items which are critical to the process.
- Problem equipment.
- Past experience i.e., which equipment has a tendency to fail often.
- Overloading/under-capacity utilisation areas.
- Up-to-date maintenance manual of the vendor.
- Imagination. Mirror at bottom level to detect tank leakages at rear, just as a reflector scans for bomb material under a car.

A short list of mandatory daily routine checks would include the following:

1. Check leaks, spills, drag-out, off-specification process solutions/liquids.

2. Schedule production in such a way so as to reduce equipment cleaning. (Case study: The earlier time table of a factory producing binding cloth was to change the red/green coloured cloth alternately every week. Later, the change was rescheduled as two months for red cloth followed by two months for green cloth. As a result, cleaning was saved, rejections were lowered, waste minimised).

3. Inspect the parts before they are fitted. This will reduce the number of final rejects.

4. Dedicate equipment to work at specified duties.

5. Improve cleaning procedure. Use mopping, dry cleanup, mechanical wall wipers/squeegees or steam or compressed air. Clean only as much as is needed.

6. Segregate waste to improve recoverability.

7. Optimise parameters (temperature, pressure, reaction time, concentration, chemicals, catalyst, etc.) to reduce resultant by-products, off-products, or isomer.

8. Evaluate each step and eliminate some if unsuitable.

The general rule while attending to maintenance is not to be in a hurry. Do not just change the filter by throwing away the old one after hastily removing it. First drain it from housing, either under gravity or pressure and collect the waste for reuse. A case study showed that in a plating shop, chrome concentration could give satisfactory service even if lowered by 9%. Chrome saved means waste saved. There is scope for waste reduction in O&M operations itself.

The common excuses one hears from O&M or process operators are:

1. 'The same has been going on in the plant since the time I joined.'

2. 'No time. As corrective maintenance engages all the time of the staff, no preventive maintenance could be undertaken.' (This is a vicious circle.)

3. 'Importance was not known.'

To overcome these obstacles, it is important that industry takes part in training programmes arranged by industry associations, National Productivity Council (NPC) or SPCB. In training programmes, they are told success stories. For example:

- A milk dairy took corrective steps on leaking containers and leaking equipment only and without any capital expenditure saved tremendous quantity of milk and avoided corresponding BOD load on ETP.

- Intelligent operating procedure saved chromium raw material input and treatment cost in an electro-plating shop, without disturbing the product quality. Moreover, it avoided closing the industry for want of chromium – an oft-repeated occurrence at this remote place.
- Participants are also taught to always ask 'Why?' to every observation. One operator saw that though there were two filters in series, the upstream one (coarse) did not get clogged and was ineffective. The redundant one was removed, and thus contaminated cartridges were reduced by 50%.
- Working can be improved by observing the mixing pattern — a Multiple Inlet Multiple Outlet (MIMO) arrangement instead of a point entry, point outlet; rectifying the weighing scale; eliminating a step (as with the filter above) or even adding a step or splitting a step, etc.).

3.2.6 Creative innovations

Waste strength reduction does not necessarily demand a set of modern technologies and a team of highly qualified experts. It may not necessarily mean high costs. The trick can be done even by use of collective common sense.

Below are examples of creative innovations tried out by different industries with good results:

Plant 1:

- Product: Ice cream, yogurt.
- Process: Mixing, pasteurising, packaging, cooling.
- Solution: (1) Increase production capacity of second container filling line. (2) Improve product metering system.
- Achievement: (1) Saving in energy and labour; (2) concomitant waste reduction by reduced overfill and spilling.

Plant 2:

- Product: Aerial man lifts.
- Process: Machining, cutting, punching, welding, plating, assembling, painting.

- Solution: Reduce the number of colour changes in painting line.
- Achievement: Reduced waste paint, reduced solvent use, reduced solvent disposal cost, reduced labour cost.

Plant 3:

- Product: Kitchen and bathroom tops.
- Process: Cutting, machining, gluing, painting, assembly.
- Solution: Install a conveyor between two mechanised work areas.
- Achievement: Reduced generation of off-specification counter tops and waste disposal costs and saving on quantity of raw materials.

Plant 4:

- Product: Cooked dried beans.
- Process: Washing, soaking, cooking, drying, packing.
- Solution: Reduce cooker venting and purging lines.
- Achievement: Reduced generation of off-specification products. Reduced expenditure on raw materials, processing and waste management.

Plant 5:

- Product: Flow-meters and flow-sensors.
- Process: Machining, welding, polishing, assembly, testing, packaging.
- Solution: Install a chiller for water used in the testing area.
- Achievement: Wide swings in water temperature prevented. This improved control of testing conditions and also reduced wastewater generation.

Plant 6:

- Product: Injection moulded plastic parts.
- Process: Drying the pellets, loading pellets, moulding, cooling, assembly and packaging.
- Solution: Install runnerless moulding equipment.

- Achievement: Reduced generation of waste, saving of raw material. Greatest impact for plastics that cannot be ground and reused, such as polycarbonate.

Plant 7:

- Product: Personal respiratory equipment.
- Process: Wave soldering, fastening, assembly, adsorbent regeneration, testing.
- Solution: Implement (1) bar code reader and (2) electronic traveller for various parts and assemblies.
- Achievement: (1) Avoided taking reject or wrong parts. Saved off-specification product. Reduced waste 11%. (2) Saved labour time on rework and to that extent production increased.

Plant 8:

- Product: Electronic controls for gas-fueled appliances.
- Process: Wave soldering, coating, testing, packaging.
- Solution: Modernisation in conformal coating process to silicon, upgrading virtual testing section, increasing production hours on automatic insertion machines, increasing the rate at which parts move through the wave solder machine.
- Achievement: Waste reduction associated with silicone conformal coatings and streamlined throughput.

Plant 9:

- Product: Aerospace hardware.
- Process: Castings refining, degreasing, coolants, machining, lathe, plating.
- Solution: Expand non-destructive testing by increasing strength.
- Achievement: Reduced generation of scrap. Early detection of flaws increased opportunities for reworking on off-specification parts.

Plant 10:

- Product: Educational materials.
- Process: Sorting, assembling, printing, packaging, ware housing.
- Solution: (1) replace plastic shrink wrap used on each boxed product and use tape to seal boxes; (2) reduce current batch size facilitating JIT (just-in-time) system.
- Achievement: (1) Saving of costs and less wastes; (2) JIT reduced inventory. Reduced quantities of outdated kits in warehouse.

Plant 11:

- Product: Electronic communication equipment.
- Process: Surface mounting, wave soldering, infra-red curing, welding, etching, assembly, testing.
- Solution: Increase/control humidity in shop.
- Achievement: Reduced number of defective components caused by static discharges, increased yield, reduced generation of scrap.

Plant 12:

- Product: Pharmaceutical products.
- Process: Batch mixing, filling dispensers, packaging.
- Solution: Reduce size of filter used after each batch is mixed.
- Achievement: Reduced expenditures for filter material and improved yield.

Plant 13:

- Product: Pharmaceutical and herbal extracts.
- Process: Solvent extraction, chromatographic separation, drying, equipment cleaning.
- Solution: Install spray drying equipment.
- Achievement: Reduced product loss during drying operation, improved yield and reduced operating cost.

3.2.7 A related case

We give below for the benefit of our readers the experience of how one industry identified waste reduction possibilities:

(a) ***Good operating practices:***

- Industry began to segregate different types of hazardous wastes. This made these wastes more amenable for recycling efforts. As a first step, the industry stopped mixing hazardous waste with non-hazardous waste.
- In the shops, maintenance scheduling was improved, record-keeping was improved to note recurring troubles and age-old procedures were streamlined with good housekeeping practices.
- The production schedule was changed with a view to minimise equipment and feedstock changeover.

(b) ***Inventory control:***

- Special paper-work was done to initiate a procedure to ensure that materials are not in stock beyond their shelf-life
- A list was prepared of all outdated materials. These were tested in the laboratory and used till effective. Shelf-life is relevant when the particular material is not stable. This complication was removed in case of stable materials.
- Industry instituted better labeling procedures to know the expiry dates in advance; and instituted a corresponding clearing house to exchange such materials that would otherwise be discarded.

(c) ***Spill and leak prevention:***

- Existing storage or stacking procedures were scrutinised to note defects (or scope for improvement).
- Improved procedures for loading-unloading and transfer operations were introduced.
- Overflow alarms and automatic shut-off valves were installed. Secondary containment and vapour recovery system was installed. Inspection and monitoring programme of potential spill or leak sources was implemented.

(d) ***Raw material modifications:***

- A search was made for increased purity of raw material to substitute for the existing one. Industry experienced a bottle-neck. However, the search continues.

(e) ***Process modifications:***

- Instituted various hardware modifications at different locations such as closed loop recycling, modified equipment or layout or piping, instituted better control on operating conditions (like flow rate, temperature, pressure and residence time).
- Instituted various process modifications at different locations such as changed process catalyst, changed from small volume containers to bulk containers to minimise discarding of empty containers.

(f) ***Cleaning and degreasing operations***

- Instituted various hardware modifications at different locations such as modified stripping-cleaning equipment, changed to mechanical stripping-cleaning devices (from solvent or other materials), modified containment procedures for cleaning units, improved draining procedures, redesigned parts/racks to reduce drag out, modified or installed rinse system, improved rinse equipment design, improved rinse equipment operation.
- Instituted various process modifications at different locations such as change to aqueous cleaners (from solvents or other materials) and reduction in the number of solvents used to make waste more amenable to recycling.

(g) ***Surface preparation and finishing:***

- Modified spray systems or equipment, substituted coating material used, improved application techniques, changed from spray to other systems.

(h) ***Product modifications:***

- The earlier product specifications were very stringent, resulting in large discards without much corresponding benefit to the client. After discussion with client, the specifications

were suitably changed with mutual consent, resulting in modified design and modified packing.

3.3. WM Techniques

3.3.1 Purpose

The reader who has come this far certainly shows a desire to find ways of handling wastes; which is better than just depositing them with the operating agency, which is 'out of sight, out of mind.' Before one reaches zero pollution, one must have zero discharge via WM through reclamation, recovery, recycle, and reuse. The strategy adopted is reduction of toxicity, mobility and volume through appropriate technology. The technology selected naturally depends on the nature of waste one is interested in to reduce/minimise, and the type of contaminants it contains (see table 8).

Table 8: Break-up of contaminants

#	Contaminants	Type break-up
1	Organic	• Organic liquids, soils, sludge, sediments • Petroleum-contaminated soils, sludge, sediments, • Solvent contaminated soils-sludge-sediments, • Rubber goods tyre-belts, polymers, etc.
2	Inorganic	• Metal-containing solutions, • Metal-containing soils-sludge-sediments, • Slag, bottom ashes, fly ash, foundry sands, • Batteries, mercury-containing materials, etc.
3	Miscellaneous	• Chemical tanks, demolition debris, transformers, ballasts etc.

Experienced managers have the following practical advice to offer:

1. Read the authorisation letter or consent issued by the SPCB and the listed hazardous wastes, non-hazardous solid wastes, air emissions and wastewater (quantity, description and quality standards).

2. Read the names of hazardous wastes again either as mentioned in the authorisation or by additionally referring to Schedule I category, Schedule II category or properties limitation (like reactivity, corrosivity, toxicity etc) from the HW Rules, 2003. Then prepare a list of the industry's wastes which falls in those categories.

3. Identify which of the above wastes can potentially be recovered. (Either refer to literature or CPCB publication 'Ready Reckoner for Hazardous Waste Management,' Ref.No. HAZWAMS/12/1998-99).

4. Identify which recycle technology will be more appropriate vis-a-vis the waste, and then select the gadget/s which can simultaneously sort out many problems. (Here again, literature or vendors in the field may help.)

5. However, before placing the order with the vendor, once again check if there are no other possibilities whereby waste generation can be prevented by change of raw materials, process, hardware, utilities or instrumentation.

6. Before finalising the technology, select one that may not need pre-treatment and which does not leave residuals that are difficult to manage.

3.3.2 Data management

The above indicates that the hazardous waste minimisation planning process requires collection of substantial data. The data should not be defective, or else the decision can be unreliable. Decision-making relies heavily on consistent, timely and accurate data. The chain is data assembly → data interpretation → data use → decision → data for checking success of the decision.

When recycling is being considered, collect data to address the following questions:

1) What type of recyclable material does the waste constitute?

2) What recycling process is used/usable?

3) Would the recovery process generate secondary hazardous waste, for example:

   a) Spent materials (like catalyst, mother liquor).
   b) Sludges listed in Schedule 1 or 2 of the HW (M & H) Rules, 1989/2003.
   c) Sludges not so listed (non-hazardous).
   d) By-products which fall in Schedule 1 or 2 of the HW (M & H) Rules, 1989/2003.

e) By-products not so listed (non-hazardous).

f) Discarded products.

g) Scrap metals.

(It will be worthwhile to try to recycle all the above seven kinds of wastes, but priority WM will be as listed at b and d above).

3.3.3 Waste reduction (WR) before waste minimisation (WM)

WR has to precede WM. It commences at the stage of procurement of raw materials and ends with using the waste as raw material. In this section, we concentrate on four aspects:

1. **Raw material control**: This includes not only the actual raw material reactants, but also the materials required for utilities, additives, work-up chemicals, water, washings, by-products, intermediate products, and catalysts. Waste also needs to be handled as carefully as the ready saleable product because if it is further contaminated by poor handling, it may lower the possibility of recovery value. Therefore, if the industry keeps one dedicated person for this purpose, the advantage will more than compensate for the expense.

2. **Raw material stocks**: Larger the stocks means not only are more funds locked up, but the risk is also increased. This risk could be in potential accidents, fire hazards or explosion and it can also be a burden, if the accumulated material becomes unusable. The modern concept, therefore, is just-in-time (JIT), which means that the industry should develop such relations with the suppliers so as to get the material with a phone call (so to speak) just at the time of charging the reactor. An exercise on demand of material and risk involved should be conducted by the industry.

3. **Process modification**: This is the heart of WR and WM efforts. This prevents waste at generation, removing any further problem of waste collection, segregation, recovery, sale, or exchange. Some modifications can be very simple while others may need highly modern technologies.

4. **Volume reduction**: This may be required either for better management and handling or as pretreatment of waste for increasing its fitness for a particular recovery technology. Both the aspects are good but the latter has real merit. Merely concentrating the waste so

that more waste can be dumped away by one truck-trip outside, is not WR. But if concentrated, for example, by de-watering, and copper is recovered from the remaining sludge (as in the electro-plating industry), it is a WR practice.

3.3.4 WR Techniques

For WR, chemical plants can employ the following techniques:

1. Substitution, by using less hazardous equipment. For example, heat transfer done through water rather than oil or high flash point chemicals or low toxicity solvents in place of halogenated ones.

2. Lowering impact by using the same chemicals but under conditions that are less hazardous, for instance, using vacuum to reduce the boiling point, or reducing temperature or pressure in a reactor, or dissolving the mass in safe solvents or preventing reactor runaway.

3. Maintaining adequate distance between different types of equipment in order to reduce hazards, for example, keeping remote controls and operator distant from the operations or strengthening the control rooms and corresponding tanks.

4. Using concentrated materials which will reduce feed quantities of dilute chemicals. This can offer advantages like reducing the size of continuous reactors or reducing the size of storage tanks. This in turn keeps the hazardous intermediates in check.

5. Setting up barricades or enclosures to isolate the equipment or sealing rooms of the warehouse, tank-farm, process-shops and plant engineering or shielding the vents on pollutants (air or wastewater). Placing remote and continuous monitors also will be useful, as also negative pressure in the reactor (as in an asbestos mill).

3.3.5 Logic

Some of the terms in the figure below need to be clarified: Waste material is that which is either lost before feeding (raw material) or which is lost after feeding (process or product loss). On-site recovery is better than off-site recovery, after transportation. The best place is on-site and the best method is if the waste can be re-used as raw material (with or without need for purification).

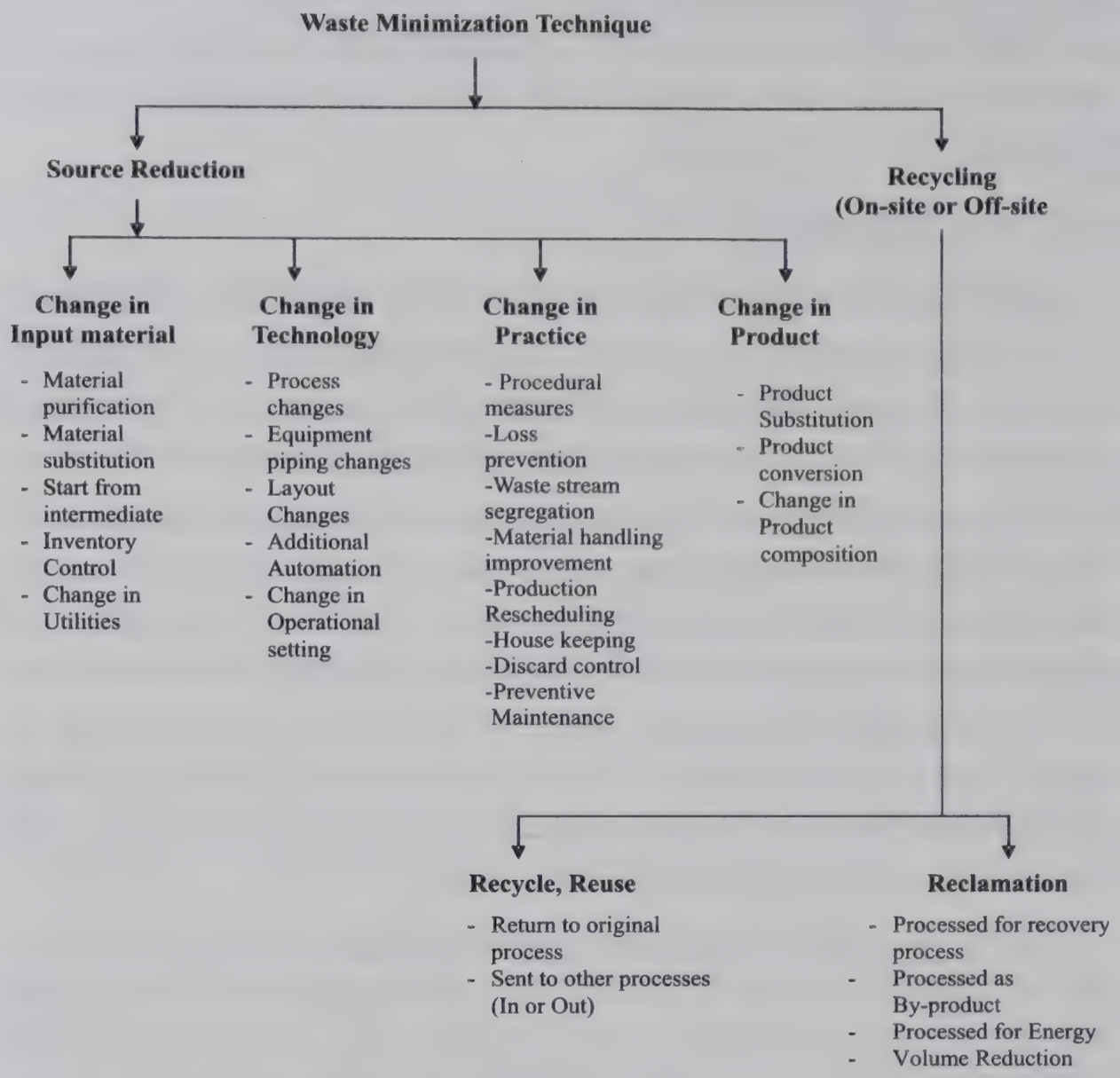


Fig 3.1 Waste minimisation techniques

For example, when in asbestos sheet making, the end-cuts or side-cuts are fed to the mixer in its green form, or when the order is for 2.5 meter sheets, changing the usual drum of three meter circumference to a five meter one. In the former, the wasted length was 0.5 meter per sheet while in the latter (by cutting the five-meter length into two), the wasted length is nil. Other examples are: in a medical instruments making unit, reverse-osmosis system was used to recover nickel-plating solution; in a textile unit, an ultrafiltration system was used to recover dyestuff from effluent, etc. Off-site recovery is normally resorted to where (1) the necessary equipment is not available on-site; (2) not enough waste is available at one point to feed the equipment (or justify erection of one on-site); or (3) recovered material has no use at the site, but is useful elsewhere. On some occasions, the supplier himself might take it back for reclamation, as

reclaimed material may fall cheaper for him than virgin for resale or may prove purer than virgin. The concept of an exchange bank can also be experimented with and appropriate advertisement issued in newspapers, at seminars or through the good offices of the SPCB or associations of industries.

Although the above discussions might give an impression that waste means only solid waste (hazardous or non-hazardous), waste can be air-borne as well (gas or suspended particulate matter). SPM control devices arrest waste material which, like solid waste, should be reused. Table 9 will help the industry to select a better technology from this viewpoint.

Table 9: Better technologies for extracting wastes

Device	Size µm & above	Effi-ciency %	Advantages	Disadvantages
Gravitational settler	50	<50	Low pressure loss, simple design, simple operation.	More space needed. Has low efficiency.
Centrifugal collector	5-25	50-90	Low-medium pressure loss, simple design-maintenance, continuous disposal of collected dust, independent of temperature, suitable for high dust loading.	High headroom is required. Gives low efficiency for small particles. Is sensitive to dust loading and flow
Wet collector			Simultaneous gas and particle removal possible. Cleans and simultaneously cools high temperature. Handles moisture-laden gases or corrosive gas. Can recover mist and achieve neutralization. Capacity for dust explosion risk minimised. Efficiency is variable	Has problems of erosion and corrosion. Wastewater is required to be treated. Offers low efficiency for small size particles. Likely to affect plume rise as it might add water vapour to plume. Contaminants should be evaluated.
Spray tower	10	80		
Cyclonic impingement	2.5	80		
Ventury	0.5	99		

Electro-static Precipitator (ESP)	>1	95-99	Offers more than 99% efficiency. Very small particles collected. Available for both wet or dry operation. Shows low pressure drop, has few moving parts and can operate at high temperature. Electrical power is needed.	High costs. Is sensitive to loading and flow rates. Relatively low efficiency for high resistivity material. Shows a tendency towards gradual imperceptible reduction in collection efficiency. Has an inherent electrical hazard.
Fabric filtration	<1	>99	Dry collection is possible. With time, degradation in performance is obvious. Small particle collection possible. Offers high efficiency.	Sensitive to velocity and high temperature, gases must be cooled/chemical degradation of filters/ condensation effects

3.3.6 Selecting a WM technology

As a preparation for selecting a final WM programme, we should be acquainted with various technologies that are available. Before we take that step, we should have some understanding about the different types of waste. Wastes can be divided into the following categories:

a. Wastes containing mainly organic contaminants,

b. Wastes containing mainly inorganic contaminants, and

c. Miscellaneous waste

These are further detailed as shown in table 10:

Table 10: Waste recycling technologies

Waste Type	Possible recycling technology
a. Wastes containing mainly organic contaminants	
Liquid organic solvent and liquid petroleum products	Distillation, energy recovery, decanting
Soils-sludge-sediments, either solvent-contaminated or petroleum-contaminated, or organic sludges	Energy recovery, decanting, thermal desorption, solvent extraction (and use as asphalt aggregate in case of petro-contaminated)
VOCs	In-situ vacuum extraction

Non-aqueous-phase liquids (NAPLs)	Pump and recover
Dissolved organics	Freeze-crystallisation
Propellant and explosives	Energy recovery, ingredient extraction, reuse and conversion to basic chemicals
Lead/acid battery cases	Energy recovery (ebonite or polyethylene), reuse as thermoplastic (polyethylene)
Rubber goods (tyres, belts)	Energy recovery, size reduction and reuse, thermolysis
Liquid manomers	Distillation, energy recovery
b. Wastes containing mainly inorganic contaminants	
Metal-containing solutions	Freeze crystallization, chemical precipitation, ion-exchange, reverse osmosis, dialysis, evaporation, cementation, electrowinning
Metal-containing soil, sludge, sediment or slag	Chemical leaching, vitrification, pyrometallurgical processing or use as construction material/raw material for cement
Abrasive blasting material, foundry sand	Use as construction material/raw material for cement, vitrification, physical separation.
Lead-acid battery internals, nickel-cadmium batteries	Chemical leaching, pyrometallurgical processing, physical separation
c. Miscellaneous waste	
Scrap chemical tanks, pipes	Decontamination and disassembly
Nonmetal structures and demolition debris	Decontamination and disassembly, use as construction material
Wood debris	Energy recovery
Transformer and ballasts	PCB flush and treat (eielectric), metal recovery (electrical)

Many industries are using these technologies especially when waste quantities are large or waste hazards are high. An indicative list is given in table 11:

Table 11: Industries using better technologies

Industry	Waste products	Waste quantity	Waste hazard
Chemical	Several	H	H
Leather	Heavy metals, sulphide	L	H
Electric/electronic	Heavy metals, chlorine, solvent	M	H
Mechanical	Oils	H	H

Metal manufacturing	Heavy metals, acid, ail	H	H
Non-metal minerals	Asbestos, cement, dust	H	L
Motor vehicles	Acid, oil, cyanide	M	H
Rubber, Plastic	Vulcanizing chemicals	M	L
Timber, Furniture	Phenol, formaldehyde	L	H

(H = High, M = Medium, L = Low)

The above table indicates the kind of technology that might prove to be a good candidate for your type of waste. In table 12 below, we examine what can be the limitations for its application and the media restrictions. All these technologies will generally address the following forms of wastes, namely:

a) Organic liquids

b) Organic solids – soils, sludge, sediment

c) Wastewater or liquid form

d) Metals containing soils, sludge, sediment, slag or solids.

Table 12: Waste technology characteristics

Technology	Contaminants	Limitations
a. Organic liquid		
Distillation	Organic solvents, petroleum, monomers	• Difference in boiling point • Impurities
Energy Recovery	Organic solvents, petroleum monomers, wood debris	• Energy content • Ash content • Impurities • May produce toxic products • Waste moisture content • Explosion hazard
Decantation	Organic solvents, petroleum	• Fluid density • Impurities
b. Organic solids, soil, sludge, sediments		
Energy recovery	Organic solvents, petroleum, monomers, thermoplastic, thermosetting polymers, rubber goods, paint debris	• Energy content • Ash content • Impurities • May produce toxic products • Waste moisture content • Explosion hazard

Thermal desorption, solvent extraction, soil vapour extraction	Volatile or semi-volatile organics	• Extraction/collection efficiency • Typically produces a mixed organic product
Re-extrusion, chemolysis	Thermoplastic, polymers	• Most applicable to single polymer type • Colour and opacity • Impurities
c. Wastewater processing		
Freeze crystallization, precipitation, Ion exchange, reverse osmosis, diffusion dialysis electrodialysis	Metals	• Requires low concentration of suspended solids, oil and grease • May require additional processing to recycle
Evaporation	Metals	• Requires low concentration of suspended solids, oil and grease • Energy-intensive
d. Metal-containing solids, soil, sludge, sediments		
Chemical leaching	Metals	• Silica content • Leachable metals in product • Slagging condition
Feed to cement kiln	Metals or inorganics	• Silica content • Iron content • Impurities
(The end use either getting energy or reusable material)		

To facilitate selection, below (table 13) is a list of different types of waste and the most appropriate technologies for minimising such waste:

Table 13: Wastes and appropriate WM strategies

#	Waste types	Possible recycle technology
1	Ash	Aggregate/construction uses, cement raw material, chemical leaching, solution processing, physical separation, pyrometallurgy, vitrification
2	Battery cases	Chemolysis, energy recovery, polymer re-extraction, reuse plastics and particulates, thermolysis

3	Battery metals	Chemical leaching, solution processing, physical separation, pyrometallurgy
4	Construction debris	Aggregate/construction uses, decontamination/ disassembly, energy recovery
5	Firing range soil	Chemical leaching, solution processing, physical separation, pyrometallurgy
6	Foundry sand	Aggregate/construction uses, cement raw material, vitrification
7	Fuel/NAPL	Pump and recover
8	Inorganic-contaminated sediments	Chemical leaching/solution processing, pyrometallurgy, vitrification
9	Inorganic-contaminated soils & sludges	Chemical leaching/solution processing, pyrometallurgy, vitrification
10	Liquid organic solvents	Decanting, distillation, energy recovery
11	Liquid petroleum products	Decanting, distillation, energy recovery
12	Mercury contamination	Bio-reduction, chemical leaching, solution processing, mercury retorting, physical separation
13	Mercury metal	Mercury distillation
14	Metal containing slag	Aggregate/construction uses, cement raw material, Chemical leaching, solution processing, pyrometallurgy, vitrification
15	Metal containing solutions	Solution processing
16	Monomers	Distillation, energy recovery
17	Organic contaminated sediments	Decanting, energy recovery, solvent extraction, thermal desorption
18	Organics-contaminated solids and sludges	Decanting, energy recovery, solvent extraction, thermal desorption
19	Paint debris	Energy recovery, thermolysis
20	Propellants & explosives	Energetic material extraction and reuse, energy recovery
21	Shredded plastic	Energy recovery, thermolysis
22	Solid polymers	Aggregate/construction uses, chemolysis, energy recovery, polymer re-extraction, reuse plastics and particulates, thermolysis
23	Spent abrasive	Aggregate/construction uses, cement raw material, physical separation, vitrification
24	Tyres and belts	Energy recovery, reuse plastics and particulates, thermolysis

25	Transformers & ballasts	PCB-containing device processing
26	Vadose zone VOCs	Vacuum extraction

Table 14 offers another way of selecting technology based on the desired objective.

Table 14: Technology options

Technology	Can be used for ?		
	Separation	Recovery	Treatment
Neutralization			Y
Precipitation by lime			Y
Precipitation by carbonate		Y	Y
Precipitation by sulfides		Y	Y
Precipitation by sodiumborohydrate		Y	Y
Oxidation reduction	Y		
Sedimentation	Y		
Centrifugation	Y		
Floatation	Y		
Filtration (by pressure/vacuum/belt/ plate-frame/ultrafiltration)	Y		
Filtration (by RO/dialysis)	Y	Y	
Electrodialysis	Y	Y	
Acid regeneration		Y	
Ion-exchange		Y	Y
Adsorption	Y	Y	
Granular activated carbon	Y		
Resin adsorption	Y	Y	
Oxidation/ozonation			Y
Dehalogenation			Y
Solvent extraction	Y	Y	

3.4. Recycling Technologies

We need to learn the details of some of the technologies which have been listed in the above tables. These are dealt in terms of usefulness, process description, process maturity, description of applicable

wastes, advantage-disadvantage and limitations of operation. The information given below is assembled from various vendors.

3.4.1 Distillation

This is a thermal method that separates and concentrates volatile organic liquids from less volatile components, offering purification and reuse. If the volume is small or if its composition varies or if there are more solids in it, then batch process is preferred. Otherwise the continuous process is more energy efficient. An on-site solvent recovery unit typically can be made available with suitable capacity range, for example, 20 to 400 litres. More efficient working is obtained if halogenated and non-halogenated solvents are not combined in the waste. Non-volatile contaminants and low-volatile liquids remain in still bottom as viscous sludge. This residue can be incinerated.

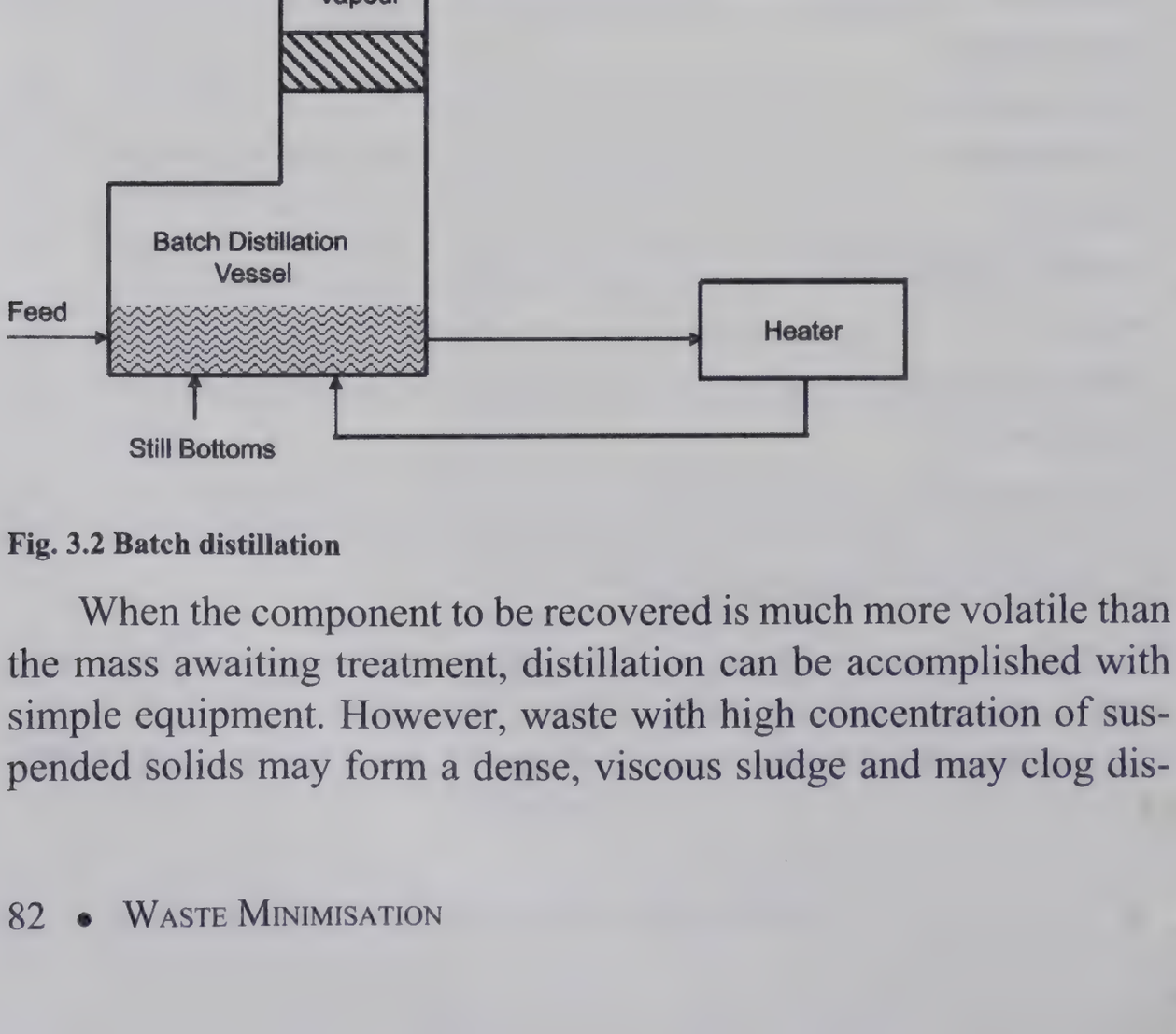


Fig. 3.2 Batch distillation

When the component to be recovered is much more volatile than the mass awaiting treatment, distillation can be accomplished with simple equipment. However, waste with high concentration of suspended solids may form a dense, viscous sludge and may clog dis-

tillation columns. High viscosity materials are difficult to process. Organics that tend to form polymers will polymerise and may clog the column or coat the heat transfer surfaces. Pre-separating chlorinated from non-chlorinated, or aliphatic from aromatic solvents, is particularly beneficial.

3.4.2 Energy recovery (general)

A number of organic wastes can be burned to recover energy in the form of steam or process heat. A good technology will be one where high proportion of carbon and hydrogen is in the organic compound, low water content, low ash content and low specific impurities. Liquid waste must be amenable to atomisation and be capable of being pumped. Precaution needs to be taken if corrosive gases are produced. If PCB or pesticide is present, precautions regarding temperature are needed. Feed solids are acceptable, depending on boiler configuration.

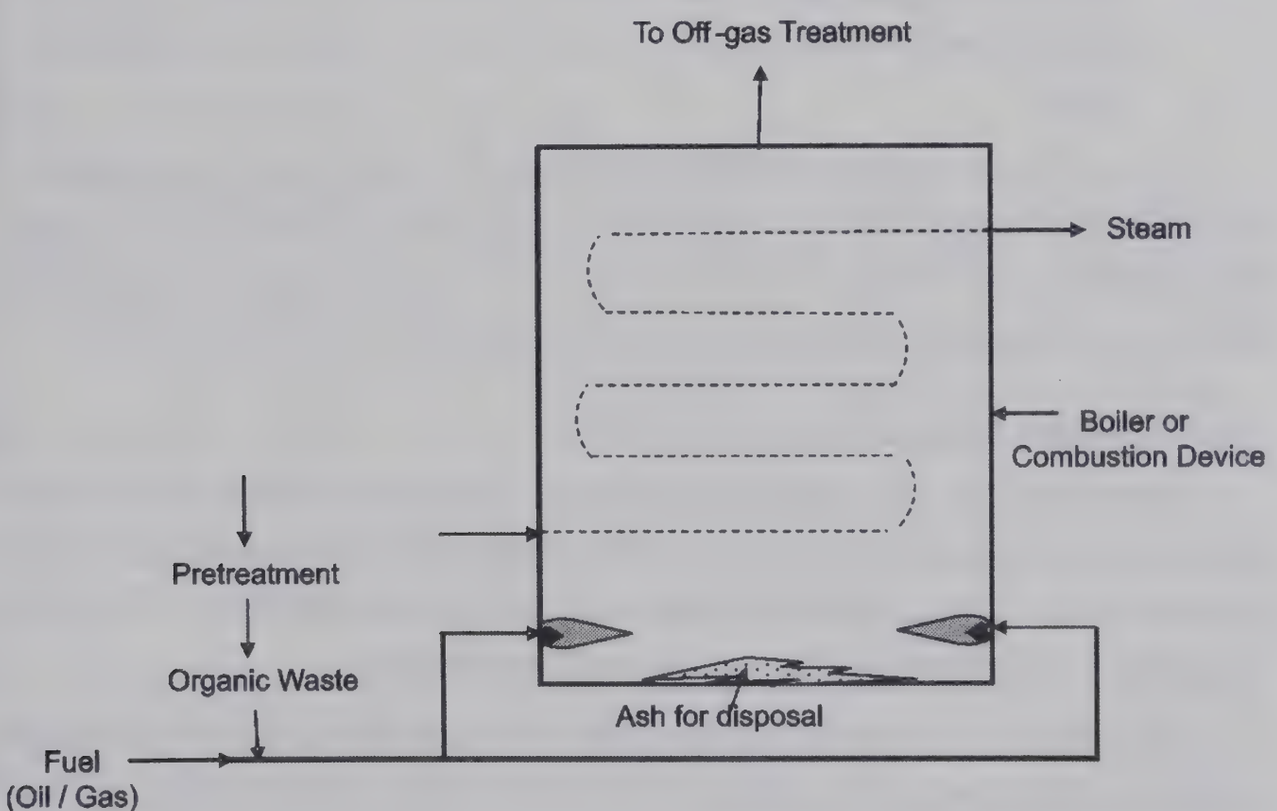


Fig. 3.3 Energy recovery application

The process is simple, as shown in figure 3.3. Where the temperature inside is as high as 1,093 ^{0}C, hazardous organic constituents will get eliminated. Unlike incineration of the waste, energy is recovered. Inorganic portion of waste will become ash, to be taken

care of separately. Process can be used for petroleum-contaminated or solvent-contaminated soils, propellants, rubber products or any other material having a heating value of 7,000 kJ/kg (3,000 Btu/lb).

The start-up of the boiler may be by fuel and then continued with waste. A useful configuration can be a fluidised bed using inert material, on which the waste is received for combustion.

If combustion is incomplete, dioxins and furans may result. There are other limitations too, such as:

- Presence of halogenated solvents in fuel which is highly undesirable as combustion gives out acidic vapours;
- One should avoid high concentration of volatile metals (arsenic, cadmium, lead, selenium, mercury) as they may result in combustion gases;
- Non-volatile metals will result in ash which is not good;
- Monitoring is needed to check presence of halides, nitrogen, phosphorus or sulphur, as they may be higher than permissible.

If one has a choice of either treating the waste and recycling as raw material or putting it to direct reuse as energy, where it has calorific values, the former will be seen to be more costly, less reliable and generating secondary waste as compared to the latter option.

3.4.3 Energy recovery (cement kiln)

Cement kilns are permitted to burn hazardous waste (for example, hazardous solvents, tyres, waste oil, etc.) after obtaining authorisation. In the USA, 26 lakh tonnes of waste are disposed of in this manner, but in India we are at the beginning stage.

The process is relatively simple. The raw material of a cement mill (i.e., limestone, clay, sand, iron ore or even some wastes) is fed (either wet or dry) at the back end of a long inclined rotary kiln. The fuel is burned at the front end. Hot gases flow upwards to the back end. The raw material, while travelling from the feed point towards the front end is sequentially heated, dehydrated, calcined, combusted, crystallised and formed into clinker by the time it reaches the front end. This is an energy intensive operation, where gas temperature has reached 2,200 ^{0}C. (Note: This is much higher than 1,480 ^{0}C

when most hazardous waste gets incinerated at a much shorter time). The process is indicated in figure 3.4.

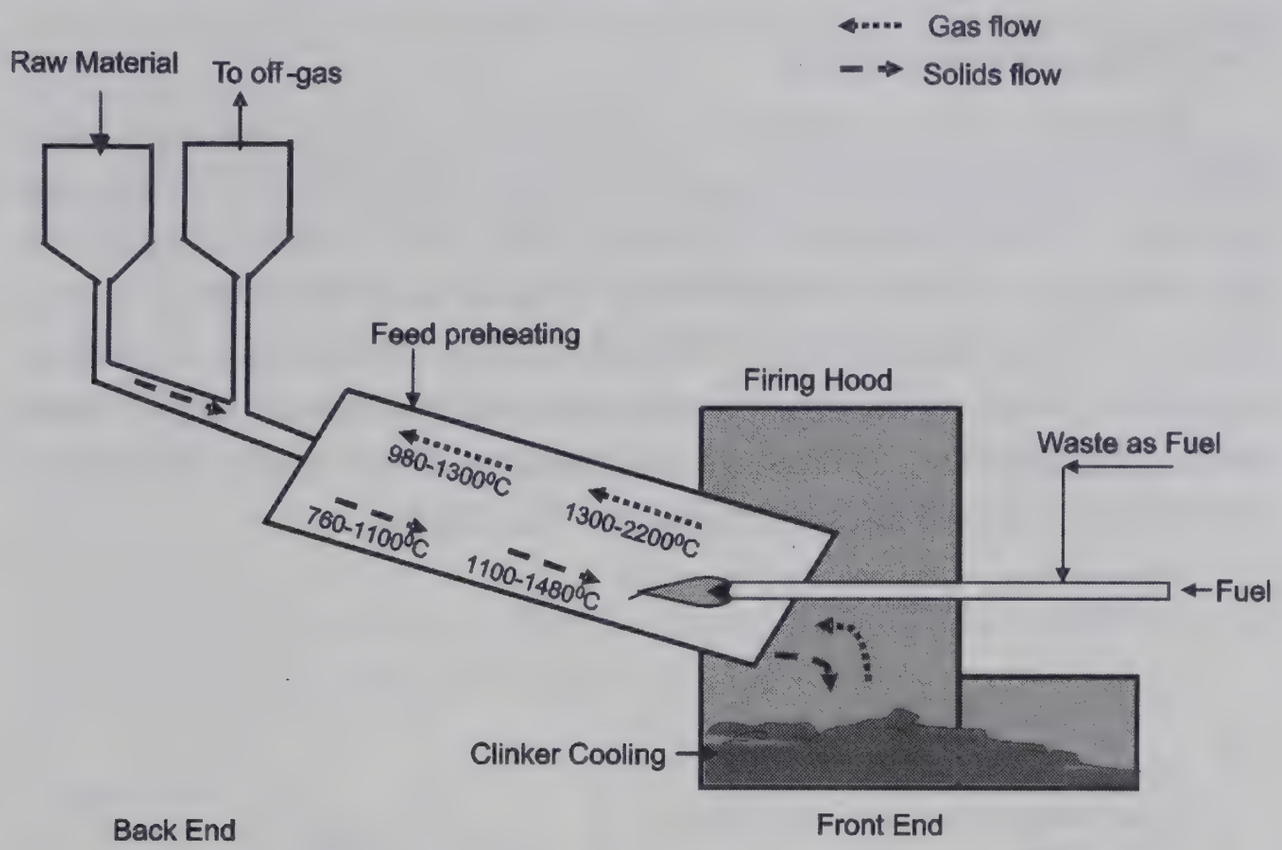


Fig. 3.4 Energy recovery in a cement kiln

Waste pre-treatment is needed such as mixing, neutralisation, drying, particle sizing, thermal separation or pyrolysis, and/or pelletisation for better results.

The use and disposal is simultaneous for liquid/gaseous wastes, for example, xylene, toluene, mixed aliphatic hydro-carbons, acetone, methyl ethyl ketone, chlorinated solvents as well as solid waste, tyres, plastic, petroleum industry's residue, etc. If there are resins, it is better to have low chlorine and low suspended solids.

Advantage: NO_X or SO_2 emissions are low. Clinker acts as a scrubber for HCl. Where chlorinated solvents are burnt, it eliminates the need for adding $CaCl_2$ and gives a low alkali cement without adding a separate additive as raw material. It is reported that some hazardous waste increases better grinding characteristics of clinker. Steel from tyres gives iron to cement, a desired element. This will be profitable for both the cement industry and the chemical industry.

Limitations: At a value of less than 25,600 kJ/kg (11,000 Btu/lb), the waste fuel is not 'hot' fuel. If it is to be burned, then it needs

special design. Waste should be uniform and consistent. It may also be noted that solid and sturdy waste presents handling difficulties.

3.4.4 Thermal desorption

Sometimes there is valuable matter in the form of 'contaminants' in the soil-sludge-sediments and filter cakes arising from production activities. Where these are of volatile and semi-volatile organic nature, there is a method available to recover and reuse these wastes instead of disposing them of. This is thermal desorption. Unlike incineration, thermal desorption removes organics rather than oxidises them. This operates at a lower temperature of 95 to 540 ^{0}C. This is not a chemical oxidation or reduction mechanism.

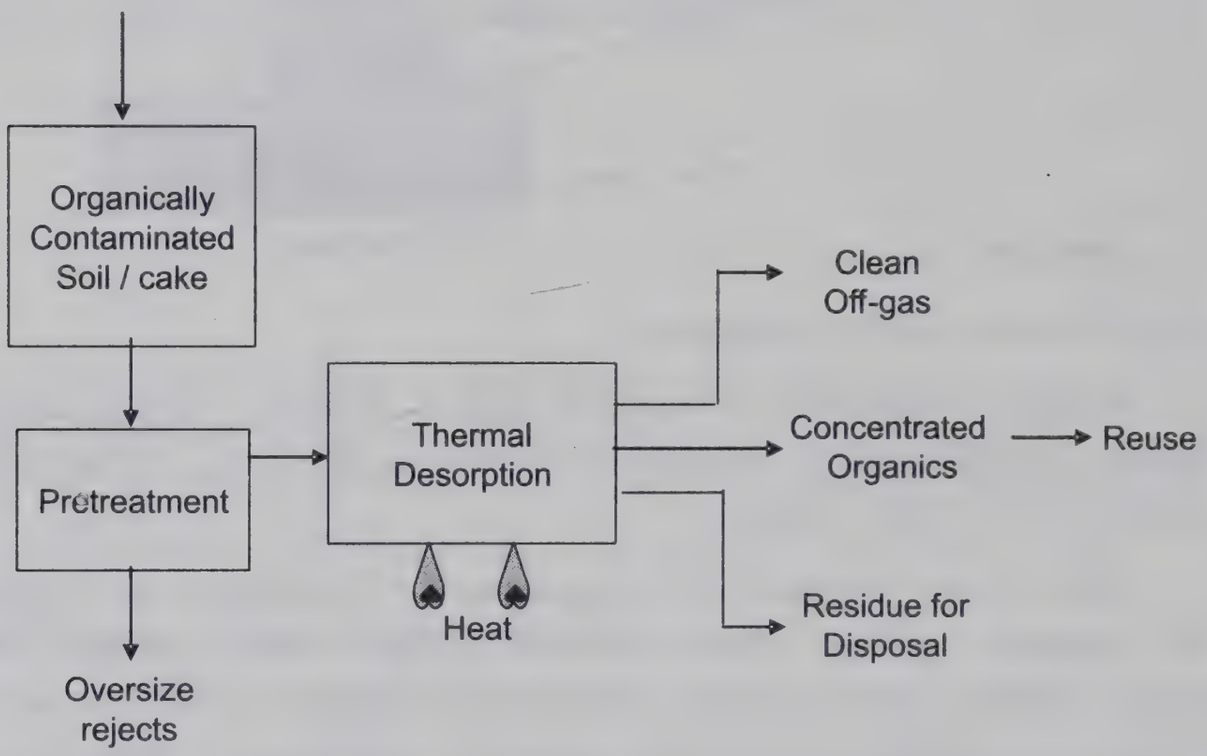


Fig 3.5 Thermal desorption process

The heating process evaporates water as well as organics. This technology is better suited to low-moisture-concentrate wastes, and small-sized particles (see figure 3.5.)

Limitation: It is capital intensive, and leaves behind traces of organic contaminants.

3.4.5 Solvent extraction

Sometimes there are 'contaminants' in the soil-sludge-sediments and filter cakes in the form of PCBs, VOCs, halogenated solvents, petroleum, etc. This can be handled by extraction using an organic

solvent. The solvent extraction process can also be used where organic contaminants are in liquid form and have reuse value.

Typical solvents include liquefied gas (butane, propane), triethylamine, etc., as shown in figure 3.6.

Advantages: Recovers organic contaminants from inorganic matrix, reduces waste volume and is useful for recycling.

Limitations: If extraction solvents are volatile or flammable, care is required for design as also for operation (risk of fire explosion maybe involved). If the mixture is composed of non-chlorinated organics it may be suitable for energy recovery or asphalt-making. If the mixture consists of various organics, then distillation is necessary before deciding on any reuse. The presence of detergents and emulsifiers reduces the performance because foam complicates separation of matrix and extraction solvents.

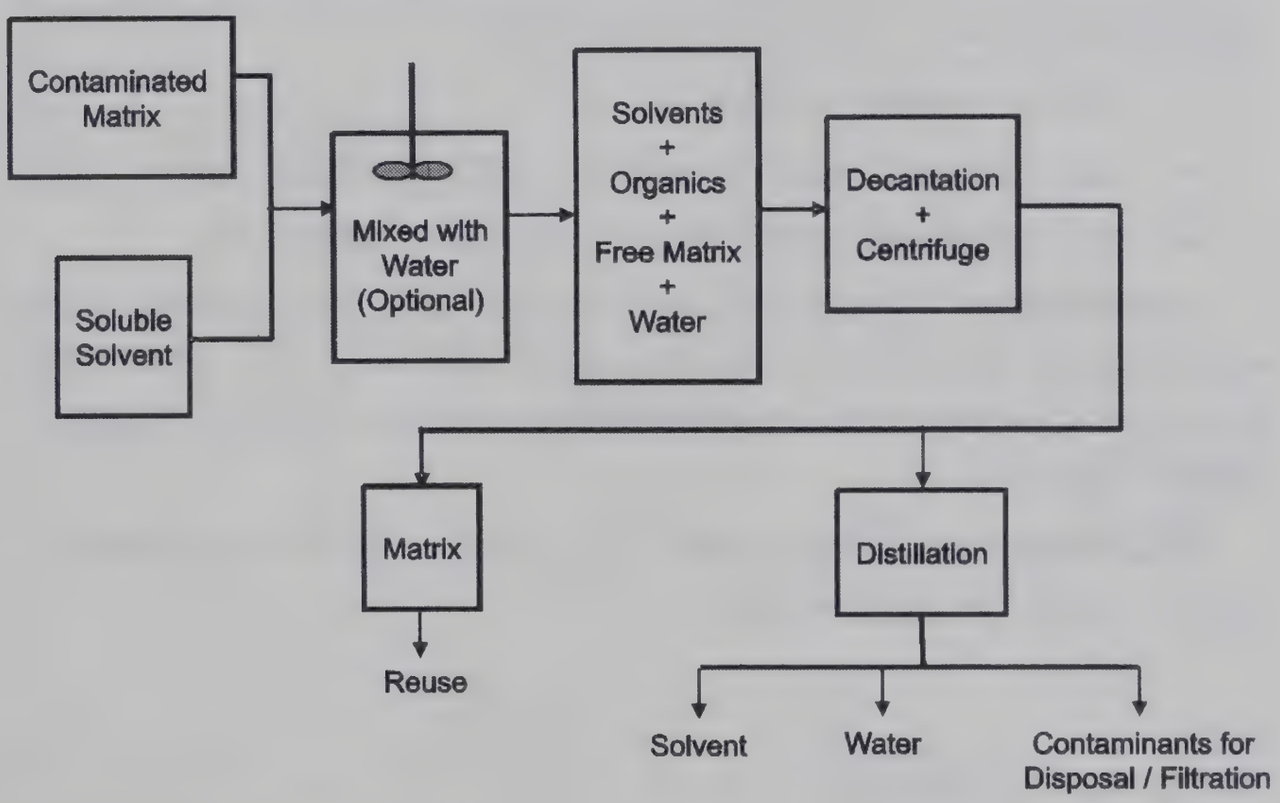


Fig 3.6 Solvent extraction process

Thorough mixing of solvent and contaminated matrix is required. Sometimes water is added. Triethylamine system extracts both water and organics. The contaminant/water/solvent mixture is heated to 55 ^{0}C, when separate water and organic phases are formed.

3.4.6 Freeze-crystallisation

This is a physical method to recover concentrated solution of organic or metal salt contaminants for reuse.

Solids are separated from liquid or liquid from liquid. For hazardous waste treatment, this process helps to separate water from the hazardous components and reduces volume. The process uses refrigeration for making the crystals of water.

This process is already in use to:

- fraction p-xylene from its polymers;
- desalt sea-water;
- purify organic chemicals; and
- concentrate fruit juices, beer, coffee, vinegar.

It has been recently applied for hazardous waste treatment and recovery purposes. It has proved useful for

- recycling acid pickling liquor;
- recycling alkaline bath used in metal finishing; and
- recovery from ammunition plants (see figure 3.7.)

Advantages: Energy efficient, no emissions, no pre-treatment needed, good performance leaving at the end only 0.01 to 0.1% of the original contaminant. As temperature is low, corrosion of equipment is avoided.

Disadvantage: High capital cost. Vessel walls are fouled by scales. Needs operational care.

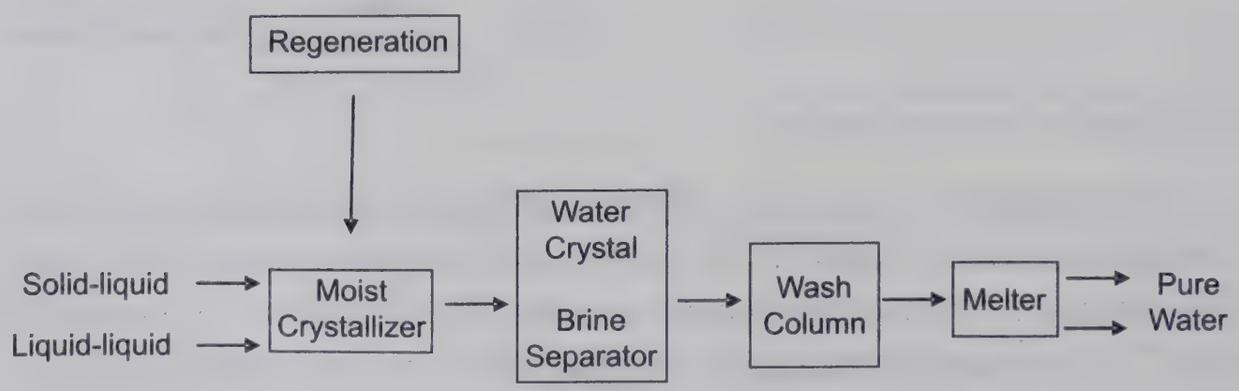


Fig. 3.7 Freeze-crystallisation process

Operational cost is mainly for electricity and labour. Capacity can be in the range of 4 to 400 lit/min in mobile units, while stationary units can be in larger systems.

3.4.7 Chemolysis

This is a depolymerisation reaction. It converts polymers (which may be upto about 150 repeating units) into monomers or short-chain oligomers (2 to 10 units). Chemolysis reduces condensed polymers by reversing the preparative chemistry bonds broken by water or alcohol at elevated temperature (see figure 3.8). As an example, PET waste is already recycled at many places by methanolysis, glycolysis or hydrolysis processes.

Chemical reaction can convert them back to their immediate precursors. Bulk thermoplastics such as HDPE, PP polystyrene, PS, PVC, however, are not easily broken down by chemical methods. These bulk plastics are more amenable to thermal treatment to produce hydrocarbon products.

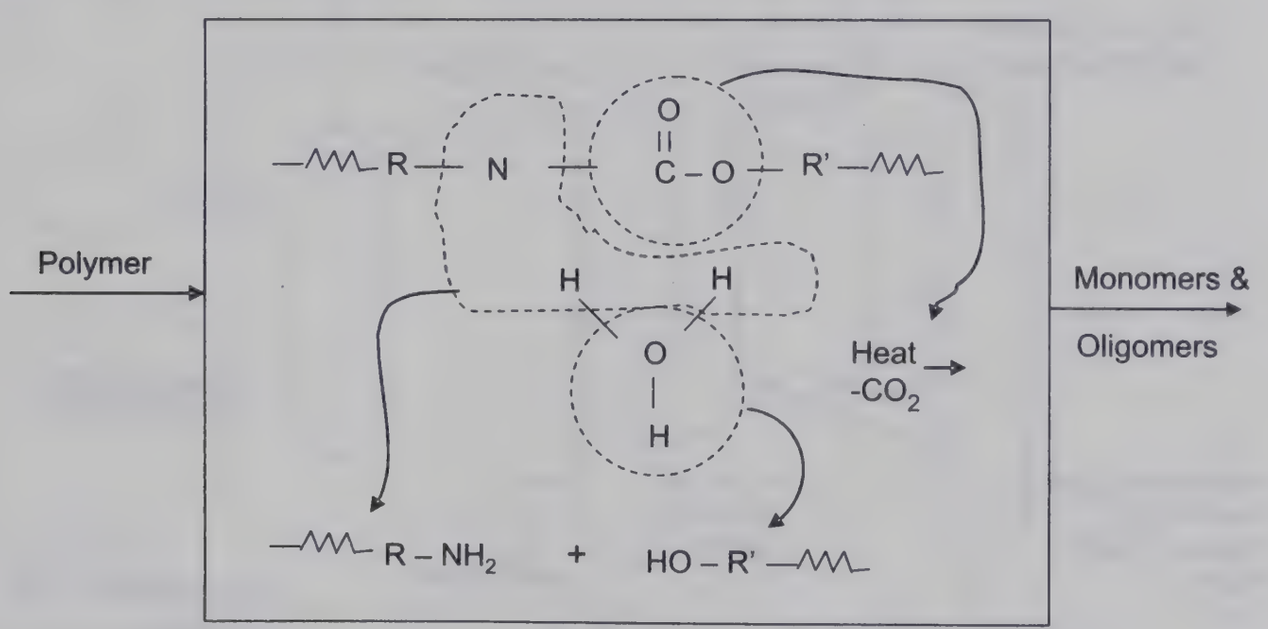


Fig 3.8 Chemolytic reaction

It has been found to be useful for high volume. Glycolysis produces short-chain oligomers. Use of excess methanol at high temperature converts to polymers and PET becomes dimethylterephthalate and ethylene glycol. Urethane can be broken down with an alkanolamine and catalyst into a concentrated emulsion of carbamates, ureas, amines and polyol. Selective dissolution can also separate mixed polymers by dissolution at a controlled temperature.

3.4.8 Thermolysis

This is a thermal conversion. It uses elevated temperature in a controlled atmosphere to produce valuable chemical monomers by processing liquid or solid organic wastes.

Process involves pyrolysis and hydrogenation or gasification. Pyrolysis is heating in the absence of air to produce liquid and gaseous hydrocarbons. Hydrogenation is to produce saturated hydrocarbon. Gasification is partial oxidation to produce synthesis gas (CO and H) used in production of organic chemicals (see figure 3.9.)

Mixed polymeric wastes can be processed without sorting. Contaminated plastic waste also can be tolerated. But chlorine (from PVC wastes) contaminates the liquid product if it is not removed. Some nitrogen-containing polymers such as nylon can produce hydrogen cyanide. Thus precautions are needed.

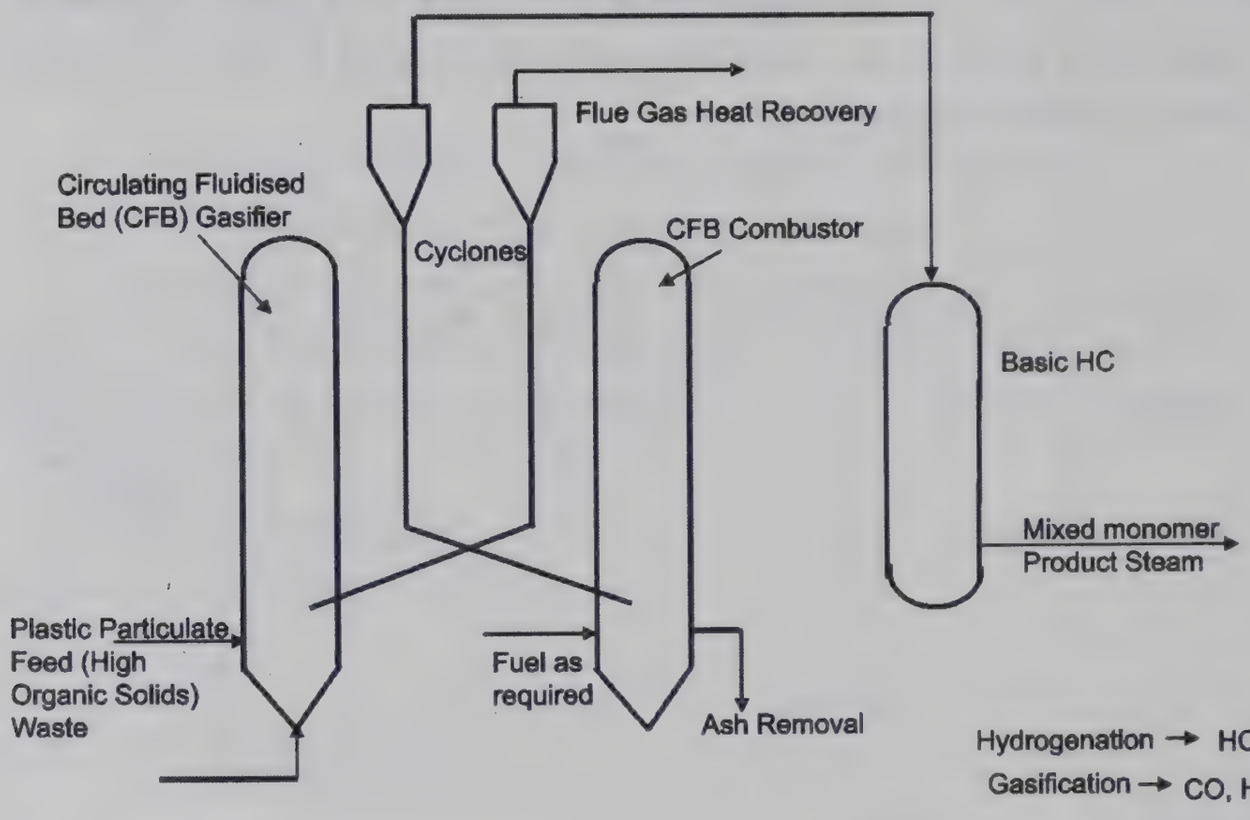


Fig. 3.9 Pyrolysis process

A circulating fluidised bed reactor can convert mixed plastic waste into monomer feedstock. Product gas ethylene is purified. Severe operating conditions (e.g., high temperature and high pressure) allow conversion of industrial wastes, scrap tyres, used oil or mixed plastic waste to basic organic components.

Further details can be sought from the industry's own collaborators/consultants to press this tool into service with confidence.

3.4.9 Chemical precipitation

This is a popular chemical method to remove and concentrate dissolved inorganics from aqueous materials with low concentrations of contaminants. The precipitated solid may be a useful product or may become useful with some additional processing (for example, sedimentation, filtration or chemical leaching/smelting to recover a salt/metal).

Standard reagents include lime (calcium hydroxide), caustic (sodium hydroxide), magnesium hydroxide, soda ash (sodium carbonate), tri-sodium phosphate, sodium sulfide, ferrous sulfide. These reagents precipitate the metals such as hydroxide, carbonates, phosphates and sulfides. This method is useful to precipitate metals like arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thalium, zinc, etc.

Precipitation is used for effluent treatment at electroplating facilities, leather tanning, electronic industry, nonferrous metal production and groundwater metal removal.

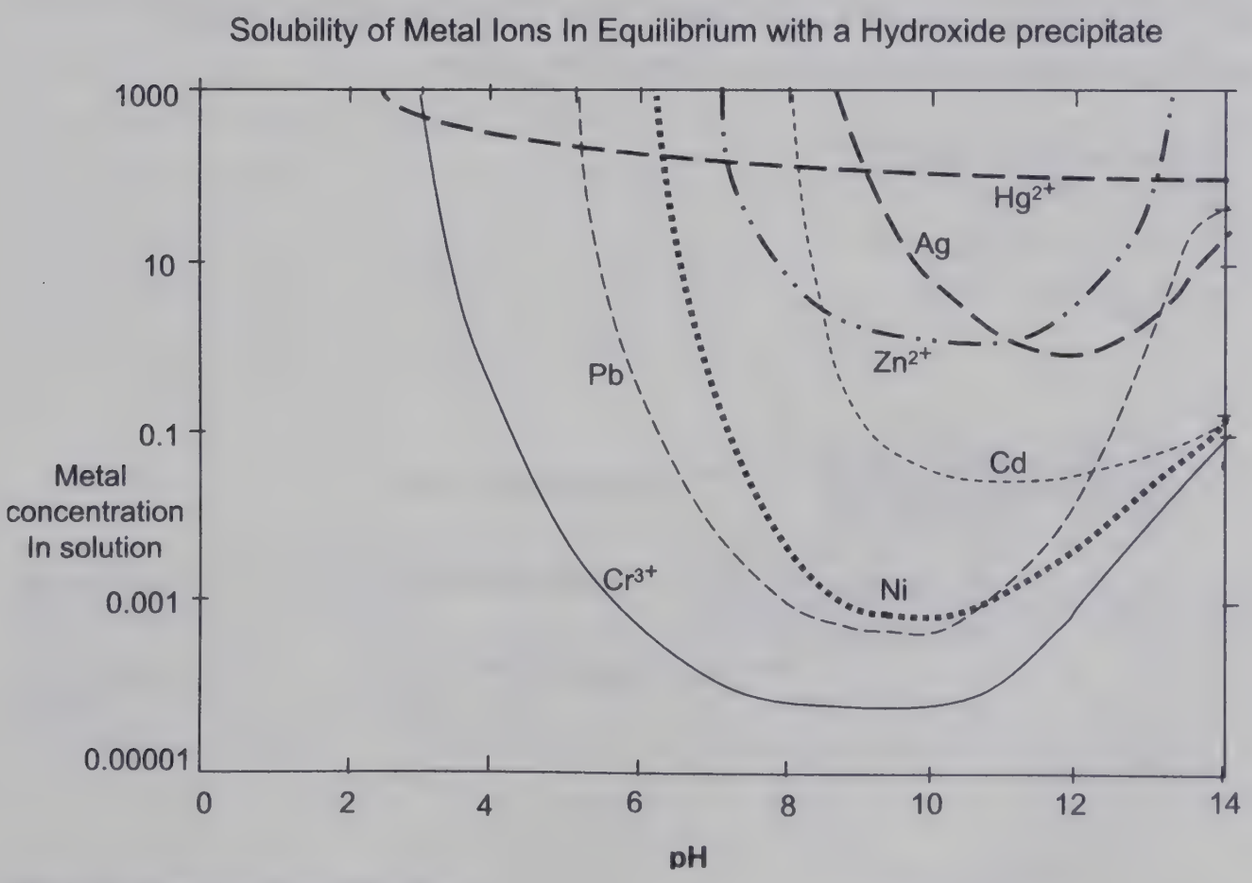


Fig 3.10 Chemical precipitation

It uses simple, low capital cost, commercially available equipment, but shows poor metal removal when chelating agents are pres-

ent. The sludge needs further processing by hydrometallurgical or pyrometallurgical methods to recover product.

The operation begins with pre-treatment such as removal of large solids, cyanide destruction and chemical reduction. The waste then enters a mixing tank, where selected reagents are added. A flocculation-coagulation tank with reagents such as alum, lime, polyelectrolyte is provided. This is followed by settling in hopper bottom tank for 90 to 150 min (see figure 3.10). This is only illustrative.

3.4.10. Ion exchange

This is a physical/chemical method to concentrate and recover dissolved organics. The process is based on the use of specifically formulated resins having an 'exchangeable' ion bound to the resin with a weak ionic bond. If the electrochemical potential of the contaminant ion is greater than that of the 'exchangeable' ion, the exchange ion goes into solution and the metal binds to the resin. Cation resins exchange positive ions like sulphate/nitrate. Resins have higher affinity for some ions than others. Ion-exchange is reversible and captured metal ions are removed from resin by regeneration. Acid is used for cation resins and as a base for anions.

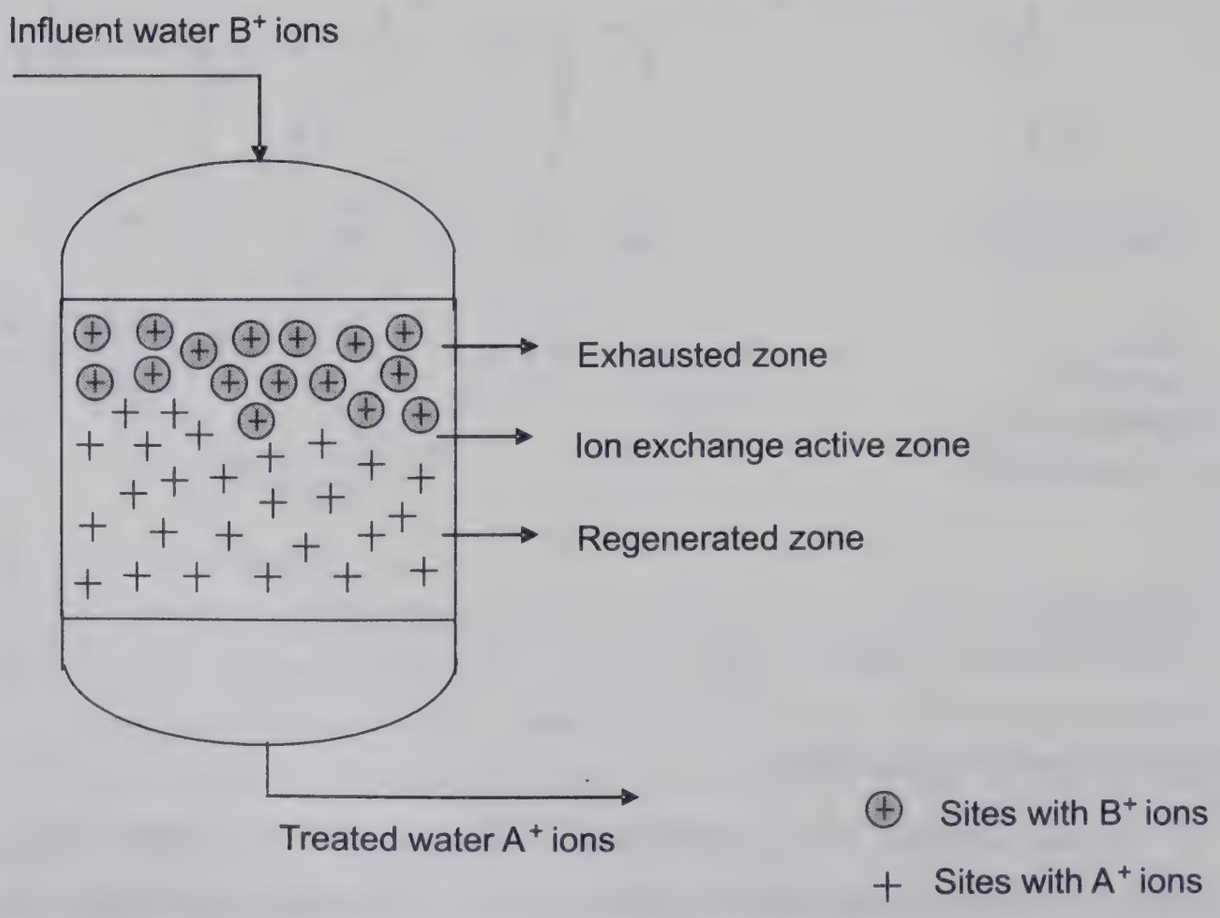


Fig. 3.11 Ion exchange operation

This technology is fully developed and hence applied to remove radionuclides (power plant waste), metals (electroplating and ground water) and softening of water. It can also be applied to nonmetallic anions such as halides, carboxylics, sulphonics, amines, etc. However, it recovers metals as a mixture, which in turn needs further treatment for isolation. Resins are prone to fouling, hence pretreatment for removing suspended solids is necessary. Oxidisers such as chromic or nitric acid degrade resins quickly.

The system can operate in any of the modes like batch, fixed bed, fluidised bed or continuous mode. There are four steps namely service, backwash, regeneration and rinse.

3.4.11 Liquid ion exchange (LIX)

LIX is a form of solvent extraction with steps such as separation, concentration, purification and recovery of dissolved contaminants from the main solution. In the LIX process, metal-borne effluent is contacted with an extractant (typically dibutyle carbitol, organophosphates, methyl isobutyle ketone, tributyle phosphate, amines etc.) where it is immiscible with water and has a high flash point. On thorough mixing, metal passes to extractant. By settling, water and metal bound organics separate. By stripping, metal and extracting organics separate. Finally, this ends with three streams, namely metal, water and extractant. It is possible to reuse all of these. This method is already used commercially in the metal industry but is very recent to the wastewater or recovery field.

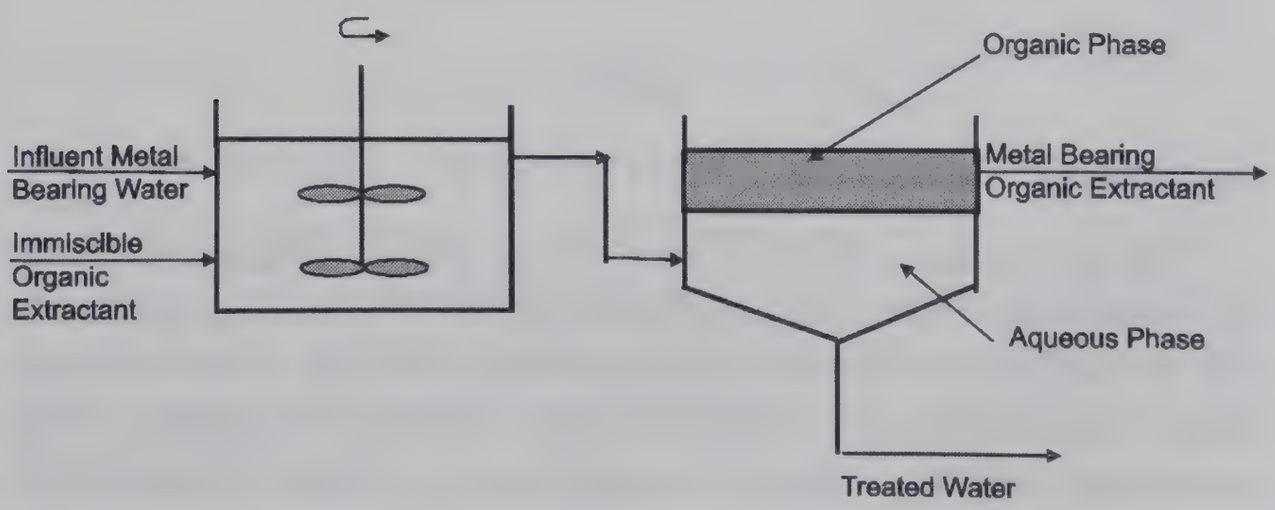


Fig. 3.12 Liquid ion exchange contact

3.4.12 Reverse osmosis (RO)

This is a physical/chemical method to concentrate and recover organics that are in a dissolved state.

Osmosis is the movement of a solvent (typically water) through a membrane that is impermeable to a solute. The normal direction of flow of salts is by gradient from the concentrated to the diluted side. Reverse osmosis reverses artificially the normal direction of flow by applying pressure on the concentrated solution. The semi-permeable membrane acts as a filter to retain the ions and particles on the concentrated side while allowing water to pass through, which is called the permeate. What does not pass through is called the concentrate. Metal or salt products are recovered from the concentrate by techniques such as evaporation, electrowinning or precipitation. For RO application, membranes that have high water permeability and low salt permeability are ideal.

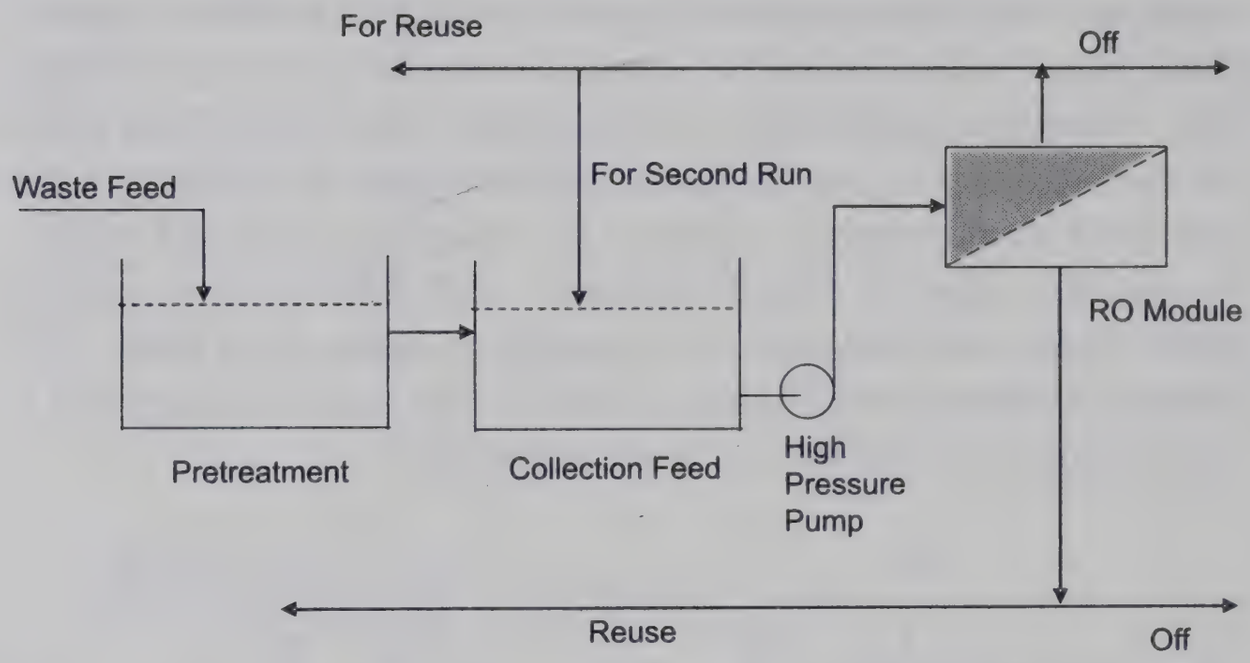


Fig. 3.13 Reverse osmosis process

The advantage is that it is less energy intensive than distillation or evaporation. However, pre-treatment needs to be done to condition the waste, since suspended solids with very high or low pH, oxidisers, nonpolar organics are not directly suitable. The ability of the membrane to retain dissolved contaminants is based on molecular size, weight and electrical charge, as well as variations of maximum pore size of the membrane. RO membranes are sensitive to fouling

and degradation. (Membrane technology is now much developed, and many of the above misgivings are already non-existent.)

Flux is defined as the flow rate of permeate per unit area of the membrane, measured as litres per square meter per day. The higher, the better. Product recovery is the ratio of the permeate flow to the feed flow. The higher, the better. Rejection measures the degree to which the metal is prevented from passing through the membrane. The less that passes, the better. Typically the metal removal is greater than 95%.

RO is different from ultrafiltration. It is on many counts superior. Table 15 will help the reader to decide on which technology is more appropriate.

Table 15: Comparative benefits of RO and ultrafiltration

Consideration for selection	Reverse osmosis	Ultrafiltration
Size of solute retained	Molecular weight <500	Molecular weight > 1000
	High salt retention	Nil salt retention
Osmotic pressure of feed solution	Can range up to >1000 psig	Negligible
Operating pressure	> 400 psig, upto 2000	10-100 psig
Nature of membrane retention	Diffusive transport barrier. Possibly molecular screening.	Molecular screening
Chemical nature of membrane	Important in affecting transport properties	Unimportant in affecting transport properties, so long as proper pore size and pore distribution are obtained
Typical membrane flux levels.	80 to 200 lit/day/sq m	800-8000 lit/day/sq m.

There are three types of membrane materials known as CA (cellulose acetate), PA (polyamide), and TFC (thin film composite). The relative performance criteria of RO membrane materials are set out below in table 16:

Table 16: Performance criteria of RO membranes

#	Particulars	CA	PA	TFC
1	Optimum temperature ^0F	33-104	33-95	33-115
2	pH	4-7	2-12	2-12
3	Salt rejection	Good	Good	Better
4	Organics retention	Good	Better	Better
5	Biological stability	Fair	Good	Good
6	Chlorine stability	Fair	Poor	Poor
7	Water-flux ratio	Good	Better	Better
8	Spiral wound configuration	Yes	No	Yes
9	Hollow-fine-fibre configuration	Yes	Yes	No.

TFC is more popular.

3.4.13 Diffusion dialysis (DD)

Diffusion dialysis is a method to recover acids or bases for reuse by processing waste water that is contaminated with dissolved metals and organics, particulate and colloidal matter and other dissolved or suspended non-ionic species.

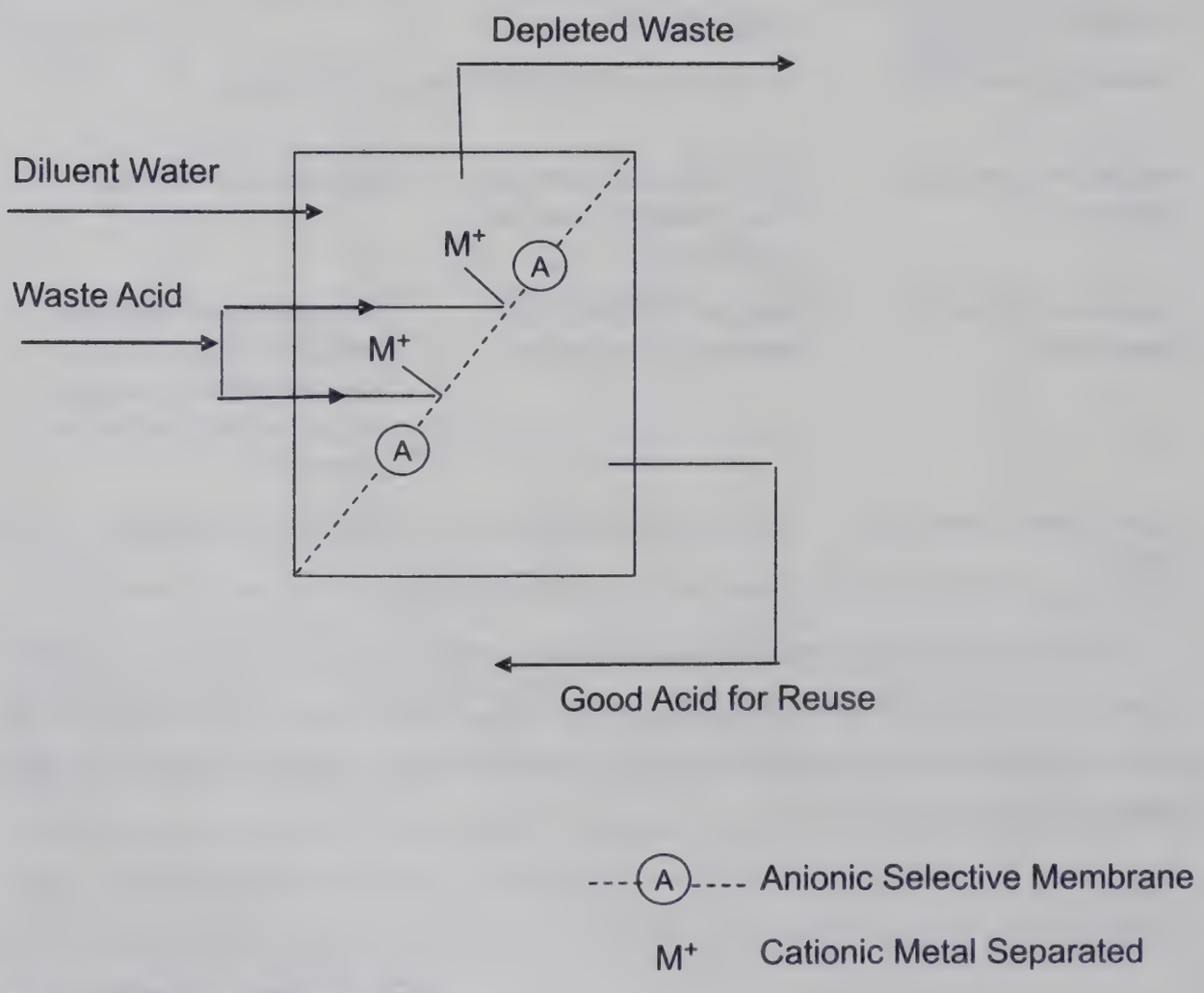


Fig 3.14 Diffusion dialysis cell

DD is a simple ionic exchange membrane technology that uses concentration gradient as the driving force to achieve separation of acids or bases from waste solutions. Anion exchange membranes allow passage of cations only (like Na+, NH_4+) and no passage to non-ionic species, particulates, colloids and even organics.

Applicable wastes recover acid values from spent pickling liquor in steel plants and spent aluminium anodising baths, mineral acids from battery waste and caustic from chemical milling waste. Waste solutions containing mixed acids (for example, HF and nitric acid) can also be recovered.

DD is advantageous as no pre-treatment is needed and the process is low-pressure, low-temperature. But membranes are susceptible to scaling and biological fouling. The economics depends on the life of the membrane. Acid recovery rate is normally 90 to 99%.

3.4.14 Electrodialysis (ED)

ED is a method to recover acids or bases for reuse by handling process wastewater and to concentrate and recover selected dissolved or suspended contaminants.

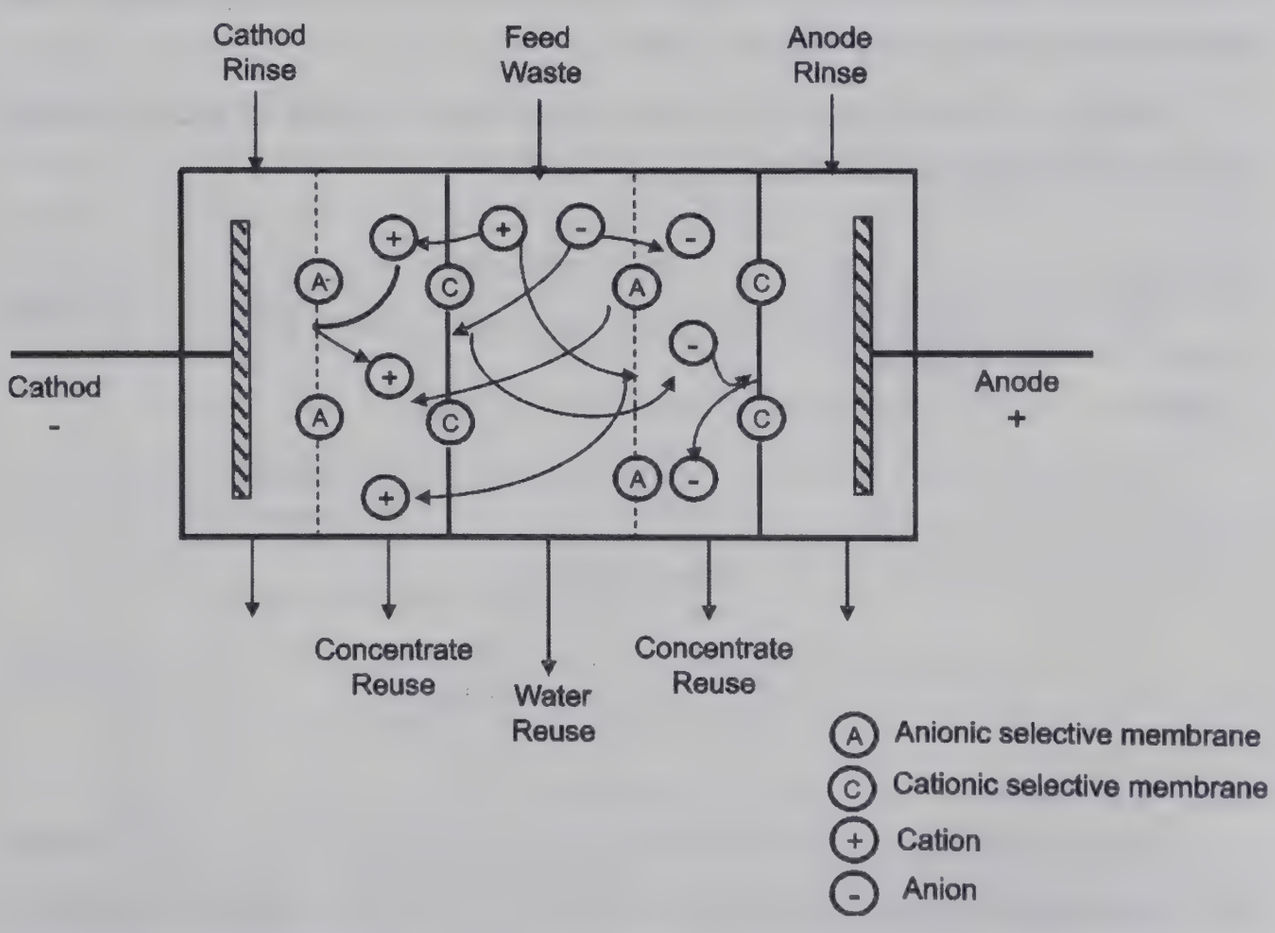


Fig. 3.15 Electrodialysis cell

Within an applied direct current field are placed hundreds of membranes with spacers in between. These ion-exchange membranes are either anion selective (permeable to chloride, sulfate anions) or cation selective. The membrane is also a barrier for dissolved non-ionic species and for suspended solids. Process wastewater/effluent is fed. Anodes and cathodes at the end impose polarity and anions or cations migrate in the opposite direction and get concentrated, from where the matter is taken out.

ED recovers caustic from spent chemicals, metal from plating rinse, and acid from spent etchants and pickling liquors, in concentrated form. However, ED requires a source of power to effect the separation. The diluate (feed depleted of its chemical values) may require additional cleanup prior to disposal, which adds to cost. The membranes are susceptible to scaling and biological fouling. Economics depends on timely availability and life of the membrane.

3.4.15 Evaporation

Evaporation is a thermal method to concentrate and recover dissolved inorganics in aqueous materials. It takes place when liquid is heated and converts to vapour, leaving behind a concentrated salt solution or slurry (see figure 3.16).

Waste stream containing more than 4,000 mg/lit of metal can be efficiently evaporated to as high as 20%.

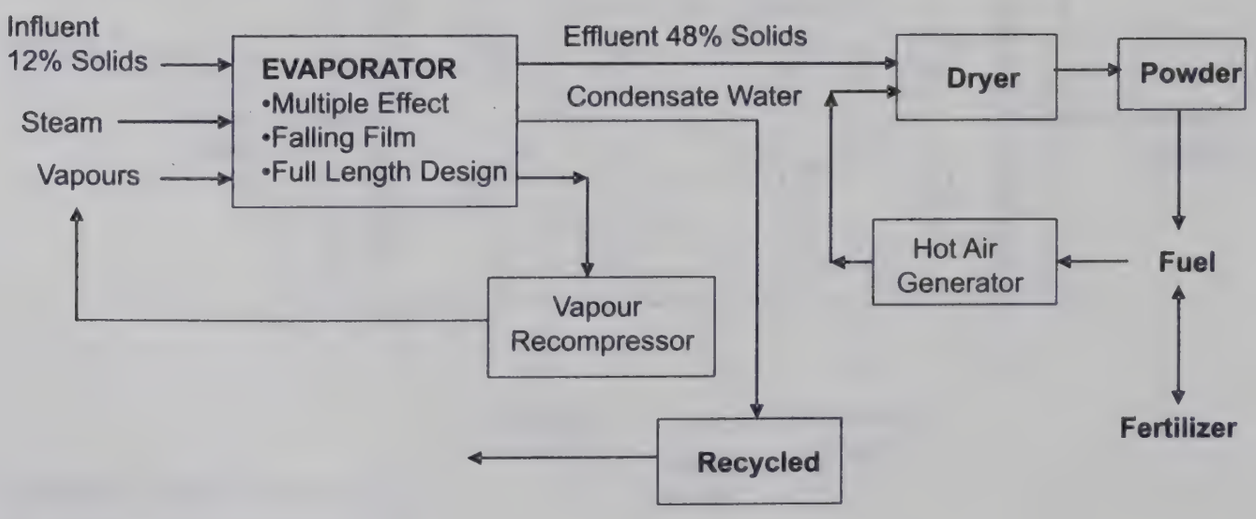


Fig. 3.16 Evaporation

Concentration by evaporation is more difficult for waste containing foam-stabilising impurities such as surfactants, fine particulates, or proteins, salts that have reduced solubility like calcium carbonate

at high temperature, compounds that decompose at higher temperature and high suspended solids concentrations. (However, though molasses distillery effluent spent-wash meets this description with part turkey red oil, suspended solids and calcium, multiple effect evaporation has been successfully tried at some places).

Advantages: Volume reduction of 80 to 99 per cent is possible depending on salts and solids. It can be reused directly but usually requires treatment like cementation (an electro-chemical method to recover metals for reuse by processing from aqueous solutions), precipitation or electrowinning (an electro-chemical method to recover elemental metal for reuse by processing moderate to high concentrated aqueous solution). Evaporated water can be condensed and used as on-site process water. But high capital cost is involved, needing energy.

3.4.16 Cement raw materials

Opportunities exist for input of non-hazardous metals-contaminated solids into cement kilns. This is a thermal method to recover inorganics, mainly aluminium, iron, and silica from solid wastes and to use the same as raw material for cement, and at the same time, to reuse organic material as fuel. Acceptable raw materials are alumina sources (spent catalysts, ceramics and refractories, coal ash, adsorbents for gases and vapours, aluminium pot liner wastes), calcium sources (lime sludge), iron sources (foundry bag-house residuals, iron mills scale), silica sources (abrasives, ceramics, clay filters and sludge, foundry sand, sand blast media, water filtration media).

There are five basic types of cement as per ASTM:

Type I = for use where special properties are not required;

Type II = for general use where sulphate resistance and lower heat generation is desired;

Type III = to maximise early strength production;

Type IV = where heat generation must be minimised;

Type V = where sulfate resistance is desired.

Main constituents of cement are C_3Si, C_2Si, C_3A and C_4AF (where C=Calcium, S=Silicate, A=Aluminium and F=Ferrite).

Fly ash can be used if it is low in sulphate and has small and spherical particles. Steel making slag is a poor raw material as it contains calcium. Four zinc smelter slag samples tested by Oklahoma University were found to be unsuitable as aggregate for Portland cement because of excessive expansion during curing. Inorganic feed to cement kilns may be selected accordingly.

3.4.17 Physical separation

Physical separation involves separating different types of particles based on physical characteristics, namely:

- Particle size (filtration or micro-filtration);
- Particle density (sedimentation or configuration);
- Magnetic properties (magnetic separation); and
- Surface properties (floatation).

Table 17: Particle separation techniques

Basic principle	Major advantage	Limitation	Example
A. Screen			
Various diameter openings allowing passage of particles with different effective sizes	High throughput continuous processing with simple inexpensive equipment	Screens can plug, fine screens are fragile, dry screening produces dust.	Screens, sieves, trammels (wet or dry)
B: Classification by settling velocity			
Different settling rates due to particle density, size or shape	High throughput continuous processing with simple inexpensive equipment	Process is difficult when high proportions of clay, silt and humic materials are present	Clarifier, elutriator, hydrocyclone
C: Magnetic separation			
Magnetic susceptibility	Recovery of a wide variety of materials when high gradient fields are used	High capital and high operating costs	Electromagnets, magnetic filter
D. Floatation			
Particle attraction to bubbles due to their surface properties	Effectiveness to fine particles	Particulate must be present at low concentrations	Air floatation columns or cells.

Limitations: Solids can generate dust problem.

3.4.18 Adsorption

By this method, the gas, liquid or solid molecule gets physically bonded with a solid, adsorbent substance. Examples are listed in table 18:

Table 18: Adsorption applications

#	Common adsorbents	And their applications for
1	Activated carbon	Solvent recovery, odour elimination, purification of gases
2	Alumina	Drying of gases, air and liquid
3	Bauxite	Treatment of petroleum fractions, drying of gases and liquids
4	Molecular sieves	Selective removal of contaminants from hydrocarbons
5	Silica gel	Drying and purification of gases.

Table 19 identifies the classes of organic compounds that are amenable to adsorption on activated carbon:

Table 19: Classes of organic compounds for adsorption

#	Class	Examples
1	Aromatic solvents	Benzene, toluene, xylene
2	Polynuclear aromatics	Naphthalene, biphenyls
3	Chlorinated aromatics	Chlorobenzene, PCB, aldrin, endrin, toxaphene, DDT
4	Phenolics	Phenol, Cresol, Resorcinol
5	High molecular weight aliphatic amines and aromatic amines	Aniline, toluene, diamine
6	Surfactants	Alkyl benzene sulphonates
7	Soluble organic dyes	Methylene blue, textile dyes
8	Fuels	Gasoline, kerosene, oil
9	Chlorinated solvents	Carbon tetrachloride, perchloroethylene
10	Aliphatic and aromatic acids	Tar acid, benzoic acid

3.4.19 Ionic liquids

Ionic liquids are environmentally benign reaction media for organic synthesis. They work at room temperature. As they are

non-volatile, non-inflammable and recyclable, they can be called a 'green' solvent. In addition, there is are possibilities of using them as a 'green' catalyst and also as a 'green' reagent. Already there are indications that this will work for unit processes like halogenation, debromination and Michael addition.

3.5 Experiences

3.5.1 Filtration

Ohio, USA EPA disseminates interesting information on this subject. A chassis designer and manufacturer was producing 470,000 automotive frames, 90,000 axle housings and 150 van extensions in a year. Die-cut and stamped metal chassis were produced. Prior to stamping, the parts were coated with an oil-based forming compound. Once the stamping was completed, the parts were washed in a hot alkaline cleaner at 70 ^{0}C and at pH 12 to remove the oil and grease. With prolonged use, oil contamination affected the efficiency of the alkaline cleaner. Every two weeks, the manufacturer was dumping considerable volume of wash, but wanted to reduce disposal costs, raw material costs and environmental damage.

The manufacturer installed two ultrafiltration (UF) modules to separate the oil waste from the cleaner. The permeates (water, cleaner, surfactant and emulsifier) were returned to the wash tank for reuse. The waste oil retentate was routed back to the process tank for concentration. Once the waste oil in the process tank reached a maximum of 15%, the tank contents were sent for recycling or disposal. The UF membranes in the main process unit are cleaned monthly. With the ultra-filtration set up, the manufacturer is recovering 30 cubic meters of permeate daily with 4.5 cubic meters of oil-forming compound per day available for reuse.

A payback period of under a year justified the fairly large capital expenditure for the manufacturer.

3.5.2 Selecting proper technology – an experience

An industry was interested in selecting proper technology for its waste. The five shortlisted candidates were electrodialysis, electrolytic metal recovery, evaporators, ion-exchange and reverse os-

mosis. The industry prepared a comparison chart and the same is reproduced below in table 20 as a model for our readers:

Table 20: Comparison chart

#	Technique	Advantages	Disadvantages
A	Electrodialysis	• Achieves higher concentration than RO or ion-exchange • Energy efficient • Organics not concentrated • Inorganic salts transport at different rates minimises unwanted inorganic return	• Feed must be filtered • Membrane sensitive to flow distribution, pH and SS • Equipment uses multi-cell stacks, incurs leakage • Chemical adjustment of recovered material • Membrane life uncertain
B	Electrolytic metal recovery	• Recovers only metals • Results in saleable non-hazardous product • Energy efficient • Low maintenance	• Solution concentration must be monitored • Fumes may form and may require hood scrubbing system • Solution heating encouraged to maximize efficiency
C	Evaporators	• Established and proven very reliable • Simple to operate • Widely applicable • Can exceed bath concentration	• Some units are energy intensive • Multi-stage countercurrent rinsing essential • Returns baths and impurities • Additional treatment may be needed to control impurities • May require pH control
D	Ion-exchange	• Low energy demand • Handles dilute feed • Returns metal as metal salt solution	• Requires tight operation and maintenance-equipment complex • Limited concentration ability • May require evaporation to increase concentration • Excess regenerate required • Feed concentration must be closely monitored
E	Reverse osmosis	• Achieves modest concentration • Small floor space required • Less energy intensive than evaporation	• Limited concentration range of operation • Fouling of membranes due to feeds high in SS, feed filtration essential • Membrane sensitive to pH • Some materials fractionally rejected • May require further concentration

3.5.3 VOC and HAP control efforts – experience

This section deals with the control of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs).

(1) *Definitions*

VOC = Any compound of carbon, except CO, CO_2, carbonic acid, metallic carbides, metallic carbonates or photochemical reactants.

HAP = Aliphatic, cyclic hydro-carbons, aromatic components, nitrogenous organic components, oxygenated organic components (e.g. alcohols, aldehydes, carboxylic acids, esters, ethers, ketones, oxides, carbonyls and oxygenators) and many VOCs. HAP also include pesticides, inorganic compounds and sulphates.

(2) *VOCs/HAPs*

VOCs/HAPs carry cancer risks, reproductive defects, respiratory track irritation, neurotoxic effects, anaemia, etc. Thus VOC/HAP control is necessary.

(3) *Sources*

VOCs and HAPs originate from various sources: biogenic, mobile sources, solvent utilisation, industrial processes, storage, transport, fuel combustion, waste disposal, etc.

They also originate from various stations: raw material storage, process vents (from reactors, separation, purification stages), equipment leaks, product storage, product transfer, ETP-ECE incinerator.

(4) *Devices*

Table 21 lists destruction and recovery routes for these substances.

(4a) *Thermal oxidation*

For successful thermal oxidation, temperature above auto-ignition, supply of oxygen, proper contact time and turbulence for contact opportunity are required. Temperature should be between 650 ^{0}C to 1,100 ^{0}C, and time – one second. For non-halogenated hydro-carbons, temperature is prescribed as 870 ^{0}C and for halogenated hydro-carbons temperature should be 1,100 ^{0}C, to reach 98%

destruction. It is necessary to have a scrubber to remove corrosive acid gases. The gadget can be with or without heat recovery. With 99.999% efficiency possible, this method is best for all processes with steady flow.

Table 21: Destruction and recovery routes

#	Destructive devices	Recovery devices
a.	Thermal oxidation	Chilled water, refrigerated brine and cryogenic condensers
b.	Catalytic oxidation	Absorbers
c.	Flares	Carbon, zeolite volume reduction system
d.	Biofilters	Membrane separation system
e.	Ultraviolet oxidation system	
f.	Plasma/electron beam devices.	

(4b) *Adsorption*

In adsorption, gas molecule goes towards solid adsorbent by bonding with it physically or chemically. If physical, it will be exothermic. VOC-HAP laden gas stream should be pretreated to remove soot, resin droplets and particles. It should also be pre-cooled. As an operating practice, it is better to keep two alternate beds, one for regeneration and one for ongoing adsorption. Bed regeneration is by heating (121–177 ^{0}C), or by applying vacuum to desorb. Adsorbents are activated charcoal or zeolite (alumina-silicate crystals) or polymeric adsorbents.

Efficiency is 95 per cent for a variety of solvents. But this method should not be used for high concentration HAPs-VOCs, and where the temperature of the adsorbent will automatically rise very high. Adsorption is preferred where the gas stream is not of mixed VOCs.

(4c) *Volume reduction*

This is also a source reduction. In adsorption process, low VOC-HAP laden stream can be concentrated. Adsorbents recommended are activated carbon, zeolite or its mixture. Twin rotating beds, one generating and one adsorbing, give efficiency of 99.999% (or 1,000 can become 1). The outlet makes further treatment and ECE (emis-

sion control equipment) requirement small. Can be done by fluidised bed configuration. Concurrent adsorption-desorption is possible.

(4d) *Absorption*

Absorption is gas phase going into liquid phase. This method has been in operation for a long period for raw material recovery/separation/purification steps. It is better suited for water soluble organic vapours or other solvents like mineral oil or non-volatile petroleum oils. The method is advantageous because the solvent can be regenerated by stripping or by disposal.

(4e) *Condensation*

Condensation is a technique for separation of VOCs by phase change technologies from gas to liquid. This is done by: (1) increasing pressure at a given temperature (compression condensation); (2) lowering temperature at constant pressure (refrigerated condensation).

Refrigerated condensation is more popular and needs units like a refrigeration unit, condensation unit and auxiliary equipment like pre-cooler, recovery/storage tank, pump/blower and piping. As a configuration, it can be either surface condensers or direct condensers. Surface condensers are preferred as recycling is possible. Both shell and tube or plate types are available and there is no contact between coolant and vent stream. Surface condensers do not have serious disposal problem as compared to direct contact condensers.

Applicability: Widely used as raw material or product recovery. This is used upstream of other ECE or alone. Useful both for halogenated or non-halogenated hydro-carbons HC.

(4f) *Membrane technology*

Membrane technology is in existence for a long time. However, application for gas is only in this decade. In this technology, gas molecule permeates through the membrane. The permeation rate depends on: (1) pressure drop i.e., pollutant loading, molecular weight of pollutant; and (2) membrane thickness, area, shape, material of construction.

Waste-gas stream is fed organic solvents which permeate the membrane. Organics in the permeate stream are then condensed and

removed as a liquid for recycle or recovery. Purified gas stream is removed as residue. Vacuum pump on the permeate side can create the necessary driving force. Generally permeate is 5 to 20 times more concentrated in VOC-HAP than the feed.

Design is either hollow fibre or spiral wound, either one stage or multi-stage. Most are synthetic polymers or may be ceramic. Thin film is fitted on support membrane. It can withstand 60 ^{0}C and its life is about three years.

Applicability: Hydrogen recovery from refinery purge, CO_2 from natural gas, oxygen/nitrogen separation and H_2S removal from sour gas stream. It is preferred to condensation/adsorption where there is low flow and high concentration waste gas stream.

VOC emission control techniques are summarised in table 22:

Table 22: VOC emission control techniques

Technology	% Efficiency	Application at stations
Enclosure	--	Container storage/container cleaning/ loading operation
Vapour absorption	90 +	Storage tanks
Vapour condensation	60 (surface condensers) and 99 (2-stage condensers)	Storage tanks
Flares	98	Storage tanks/ enclosed (concentrated streams)
Refrigeration	93-97 98	Truck, railcar, ship, barge loading storage tank
Vapour recovery	90-98	Truck, railcar, ship, barge loading
Vapour balancing system	99	Truck, railcar, ship, barge loading storage tank
Submerged loading	65	Truck, railcar, ship, barge loading drum loading
Internal floating roof tank	90-95	Fixed roof tank
High pressure tank	85	Storage tank
Leak detection and repairs	33 valves 44 pumps	Pumping and piping work
Spill response	50	All spills

4

WRITING A WASTE MINIMISATION PROGRAMME

4.1 Human Resources

4.1.1 The team captain

To a great extent, the success or failure of a waste minimisation programme depends on its driving force, which is provided by the team captain – the leader and motivator. His or her role being pivotal, their own conviction as regards WM or rather, zero discharge, is of paramount importance. Their job will be to make their teammates equally convinced of the need for zero discharge. This needs communication skills and a spirit of team-work (see table 1).

Table 1: A team captain's skills

Skill	Purpose	Target group	Characteristics of the group
Technical	To arrive at correct prioritization and designing	Staff at various levels	Initially a group of cynical members, consisting of chemist, chemical engineer, mechanical engineer, raw material procurer, product seller (which includes by-product and waste product) and statistician.
Financial	To get permission and funds	Management	Initially reluctant to release resources, but forced to consider such allocations in the face of pressures for environment-friendly technology.
Public relations	Disseminating success stories	Mixed	SPCB, judiciary where involved, NGOs, the fellow quality circle members and participants at association workshops.

Who should be the leader is a frequently asked question. Should he or she be the environmental engineer of the factory who knows the workings of the SPCB, or the production engineer who can

schedule or reschedule the manufacturing process, or the chemical engineer or chemist who knows the process and process control, or a person from overall management cadre? Anyone of them, indeed, can become the leader, provided they have the ability to reach out to their team and communicate well with them. It is, however, found beneficial in the long run to have two people at the helm of affairs instead of only one.

4.1.2 Waste Minimisation Organisation

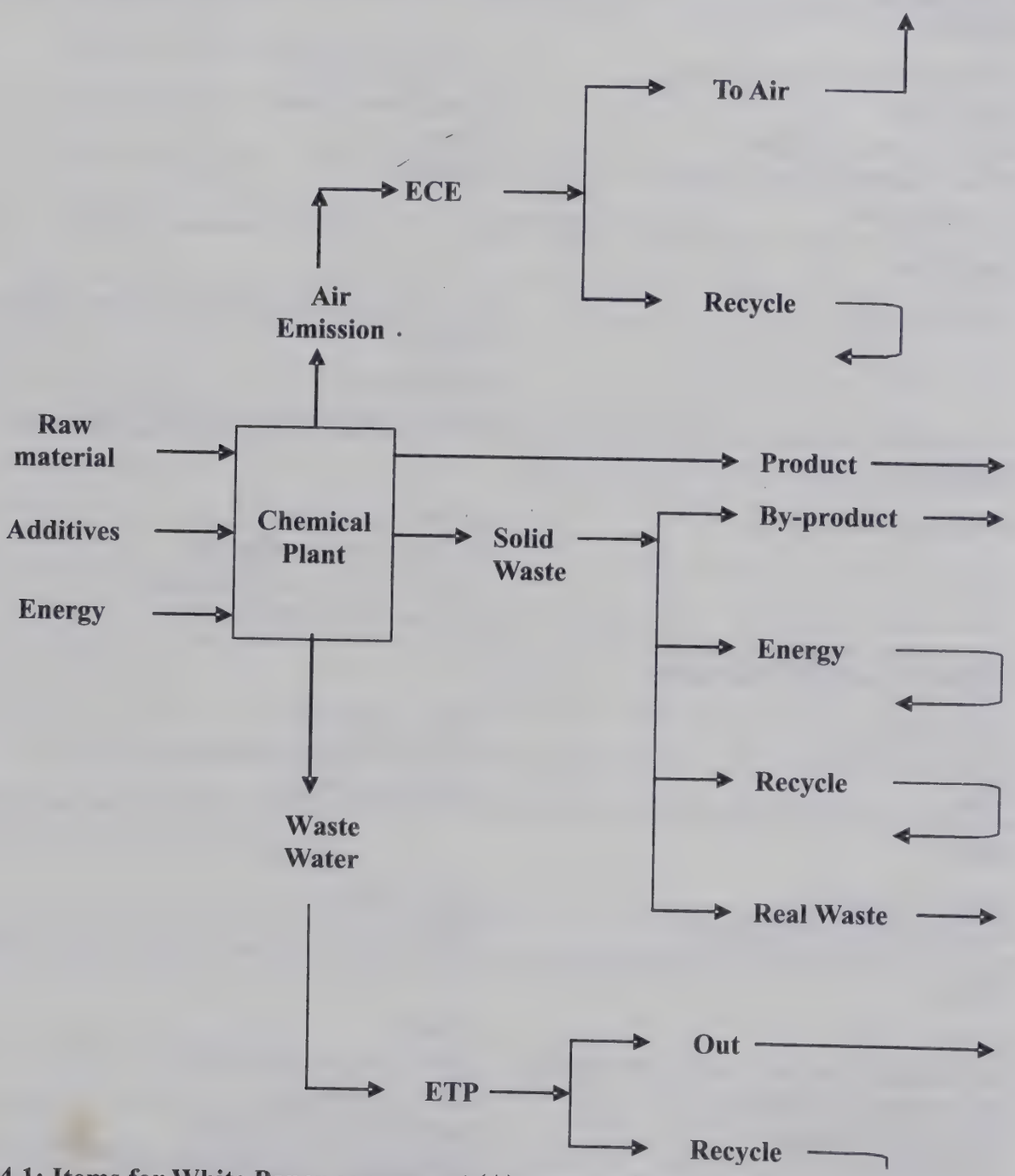


Fig 4.1: Items for White Paper component (A) preparation canvas

The captain can hardly win the battle as a one-person army. A team of people, termed the Waste Minimisation Organisation (WMO) needs to be developed. To begin with, the WMO will have

to prepare a White Paper on WM. This paper will have two components: (A) scope of the activity and (B) preparation required. For component (A), figure 4.1 shows the maximum coverage, and for component (B), table 2 below shows the maximum number of items of preparation.

Table 2: Items for White Paper component (B) preparation

Name of process reaction/waste recovery reaction	
Supply side	**Resultant side**
Utilities	
Cooling tower make-up water	Cooling purging
Boiler feed	Boiler blow down
Cooling tower additives	Spent oil
Water treatment chemicals	Used oil
Lubricating oil	
Reactants	
Raw materials	Unreacted raw materials and impurities
	Product
	By-products
	Discarded and off-spec products
Solvents	
Solvents make-up	Solvent loss in air
	Solvent loss in effluents
	Solvent loss in solid wastes
	Solvent reappearing
Aid and work-up chemicals	
Catalysts	Waste catalysts
Absorbents	Contaminated absorbents
Filters	Used, dirty filters
Water	
Water for process	Wastewater
Water for product washing	Mother liquor
Other	
Drying	Moisture
Packaging material incoming/outgoing	Odour/gaseous emissions
Maintenance material	Waste packings
Laboratory reagents	Maintenance oil, debris
Fork-lifters	Scrap equipment and piping
	Asbestos
	Laboratory washings
	Vehicle repairs waste and batteries
	Transformer oils

In addition to the above, the other aspects to be considered are:

- The present legal relations with the SPCB, NGOs, environment brigade, district collector/commissioner.
- WM technologies available in the country.
- Barriers that might come in the way.
- Conducting a brainwashing session.
- Conducting a brainstorming session.
- Analysis of every unit operation, unit process and reactor to assess the scope for WM.
- Periodical review meetings.
- Prioritisation, implementation and rating.
- Syllabus for future training programmes.

The WMO will need assistance from time to time from different sources. These may include associations of industries, either on the basis of geographical location or on the basis of types of industries. For product quality there are Quality Circle meetings, and these too can be pressed into service for the purpose of waste management. Government officers from the Inspectorate of Factories, Pollution Control Boards, universities and outside consultants can be of use, but there should not be too much dependence on them. Internal evaluations are more important for success since the problems are better known to internal operators, as well as runaway episodes. Insiders have only one handicap and that is 'tunnel vision'. This handicap can be overcome by training and by ensuring that the staff keep abreast of the latest developments.

It is necessary that the management gives appropriate incentives to the team leader, to the team and to the outsiders who help.

4.2 Crossing barriers

Invariably, a WM programme will initially meet with objections from all sides, though the degree may vary. It may be from the finance section citing paucity of funds, or from the purchase department that the new raw materials line cannot be developed quickly or from the quality control department that analysis methods for new raw materials or recycled waste are not available. The general en-

gineering department will claim that neither space is available for relocation, service and utilities, nor is labour, and the environment section will say that the amended consent or authorisation is not yet obtained. Finally, the production group will insist that the proposed measures are bound to decrease output at least temporarily.

The barriers, however, will disappear once the higher echelons of management support the WM scheme, making it loud and clear that the WM programme will eventually reduce the risks and occupational hazards to the workers while simultaneously fulfilling the legal requirements.

Some of the objections, however, may be genuine. Solutions therefore have to be kept in mind in advance. It may be worthwhile to examine some examples of hurdles faced and the solutions to overcome them. These are laid out in table 3:

Table 3: Hurdles and solutions to a WM programme

#	Hurdle	Rationale
1	Revised operation procedure may reduce waste but may produce bottleneck that will decrease overall production rate.	This will be only a transitional phase. Once streamlined, a steady state comparable to the existing one will be established.
2	Production will be stopped while the new process equipment is being installed.	A temporary phase, and the time or production lost will be made up.
3	New piece of equipment or technology has not been demonstrated in a similar service. It may not work here.	Pilot scale has been proven and a commitment is obtained from the vendor.
4	Labour may not like to change the routine.	Appropriate training will be imparted, and change in product-mix is a normal phenomenon in industry.
5	Adequate space is not available to accommodate installation of new equipment.	Redesign the workplace.
6	Adequate utilities are not available to support the installed new equipment.	This is covered by feasibility step and supplement is planned.
7	Proper engineering/construction staff are not available for installation of new equipment and in time.	External contract can be considered.

8	Maintenance load may be increased.	If predictive and preventive maintenance is done, corrective or emergency maintenance will be reduced.
9	More intensive QC will be required.	This will be supplemented.
10	More rework may be needed.	This is for better reclamation.
11	Changes in the product characteristics may affect customer acceptance.	The intention is to produce a superior product, a saleable by-product and recyclable raw material.
12	There is not enough money to fund the project.	The modern environmental laws of the land are strong and they are being aggressively enforced by the authorities.
13	Existing stock (or market commitments) will delay the replacement of a hazardous material with a non-hazardous substitute.	Time frame of process change-over and market commitments can be tallied.
14	A programme to reduce inventory (to avoid material deterioration and reprocessing) may lead to 'no stock' situation during high product demand.	Inventory control will prevent such extremes.
15	Accepting another plant's waste as a feedstock may require a lengthy resolution of regulatory issues.	SPCB is very keen to encourage waste recycling and hence change in consent or authorization conditions will be expedited.
16	Use of new non-hazardous raw material will adversely impact the existing ETP	This is taken in feasibility step and ETP will be taken for upgradation.

Offering solutions to the objections will indirectly prepare the team for the brainstorming session.

The WM leader needs to arrange a session of all departmental heads involved in the WM programme. When they have a sense of participation, they are less likely to oppose the programme. It is better to send out a list of questions that the respective departments need to answer, such as the ones listed in table 4:

Table 4: Questions to departments on WM

#	Question to pose to	Subject
1	Process engineer	• What is the life of the present product? • What is the life of the present process? • What are competing producers developing, both in terms of product and process?
2	Chemists	• What are principle factors affecting our present yield, conversion, and selectivity? • If reaction is reversible, can by-product be back-reacted to incoming raw material or converted to other reusable product? • If non-saleable products are homologues of the reactants or intermediates, how can they be converted and recycled? • What are other catalysts possible? • Are we using excess reactants or inerts, and if yes, why? • Are we using excess air, water, solvents and if yes, let us ask why?
3	Separation specialist	• How can energy needs be minimised? • How can gas/water streams be minimised? • How to arrest traces? • What alternatives exist to the heating, cooling, reheating cycles?
4	Environment specialist	• Are we meeting all existing standards laid by the SPCB? • Are any standards likely to be made more stringent? • Have we declared all hazardous waste and pollutants in our application? • Have we received any complaint, show-cause notice either from Factory Inspectorate, SPCB or public?
5	Energy specialist	• Is air-fuel ratio appropriate? • Is co-generation possible in case we are throttling the steam, or is waste steam adequate for us?
6	Evaluator	• In the final analysis, should we continue the present practice and attract uncomfortable legal situations or revise the present practice in favour of WM?

Reducing the waste at the point of generation itself or by recycling it was not specially important in the past. It has gained significance now. In future, it will become still more important based on evidence of such a WM programme. The climate is conducive for designing a WM programme that the higher management will promptly favour.

4.3 Assessing options

4.3.1 Formulate concepts

In an industry, there are a large variety of products, processes, unit operations, and dedicated reactors. It is not practical to take all of them simultaneously for deeper study. A sequential attempt is favoured and selection will be dictated by factors that may vary. The industry therefore has to decide:

- What wastes are of interest and their hierarchy (to fix the priority)?
- How to define waste reduction (to fix the objectives)?
- What factors affect the quantity of waste available for WR?
- Minimising which waste will get the industry more credit and from whom – SPCB, public or management?

The pollution control authorities in California USA have divided waste into five types. Table 5 can be used for preparing the hierarchy of wastes.

Table 5: Preparing a hierarchy of wastes

#	Type	Waste described
1	I-waste	Unused commercial chemicals that are still in packages and no more useful.
2	II-waste	Process waste, which can be recycled economically and technologically and without pre-treatment
3	III-waste	Process waste, which can be recycled economically and technologically but requiring pre-treatment or purification
4	IV-waste	Process waste, which is presently either not economically or technologically feasible for recycling
5	V-waste	Wastes that are undesirable to recycle

The above classification gives us some insight into how to deal with such wastes. Type-V waste has no scope for recycling and may be destroyed by any of the established and authorised modes. A continuous search in the literature and journals needs to be made to see if Type-IV waste could become either Type-II or Type-III tomorrow. Type-I may be easier to get rid of, if the industry has good business contacts with original suppliers or if fellow industries need such materials. In this context, the CPCB publication already referred to

('Ready Reckoner: Hazardous Waste Management') will assist the reader as it examines many wastes and indicates whether or not they can be recycled.

4.3.2 Designing the WM programme

Designing and implementing the WM programme is bound to be an uphill task. The likely hurdles will be:

- Where the cost of disposal is less than the cost of recycling, (and where the mode of disposal is accepted by authorities and not objected to by the public);
- Where the cost of raw materials, freshly procured from the supplier, is lesser than the cost of the proposed recycled material involved;
- Where the purity of raw materials, freshly procured from the supplier, is better than the quality of the proposed recycled material;
- Where the reclaimed material has no demand beyond the factory walls as there are no recycling or exchange centers;
- Where a lot of administrative paperwork is required for waste transfer for off-site recycling. This is cumbersome and time-consuming, more so if interstate transport is involved.

The management will want to know what is the recovery potential of the concerned waste. The broadly acceptable avenues are:

- Energy recovery from the concentrated organic liquid waste (for example, incineration heat recovery from organic liquids and oil);
- Recovery of materials from concentrated organic liquid waste (for example, distillation and recovery of waste solvents);
- Recovery of metals from industrial sludge and plating waste (for instance, recovery of metals such as chromium, copper, nickel, etc., from the spent bath).

When designing a WM programme, the first item that comes under scrutiny is the feed. A study of the MSDS (material safety data sheets) will show the degree of hazard of the raw material that is presently used. Research on the MSDS of the raw material selected

as a replacement will reveal its stability, toxicity, flammability, reactivity, LD 50 mg/kg on rats, odour and in general, the extent of its hazardous nature. Switching to less hazardous raw material is more likely to be accepted by the management as:

- Hazardous raw material is a risk to the industry's workers and to its property.
- Hazardous waste is a risk to the transporter, to the environment and to the people handling the landfill or incinerator.
- Hazardous product using hazardous raw material is a constant risk to users, i.e., our own customers.
- Coverage under the Public Liability Insurance Act will be applicable.

The following five logical steps (listed in table 6) will help the reader to make a proper selection:

Table 6: Logical steps for WR

Step	Action	Study
One	Select one unit operation or one unit process or one reactor	Examine • all Inputs as detailed in component (A) fig. 4.1 • all resultant side effects detailed in component (A) fig. 4.1 • risk history
Two	Imagine WR possibilities for every facet	Prepare a format for relevant items from fig. 4.1 and quantify them.
Three	Select the two best candidates A and B from among the several options, and take one for deeper study.	Design effort by collective wisdom of chemist, chemical engineer, mechanical engineer, utility engineer, outside consultant.
Four	Take trials successively on • laboratory scale • bench scale • pilot scale.	Note down observations P or Q or R
Five	If observation P, i.e., best solution	Scale-up the plant details. Finalise. The search ends.
Five	If observation Q, i.e,, no solution	Start research once again (step one onwards).
Five	If observation R, i.e., only a medium solution	• Either (R-1), modern technology has not been hitherto tried – so restart by going back to step three. • Or (R-2), go for option (B) and restart by going back to step three.

4.3.3 Flowsheet analysis

This is another way of finding one's options. As a first step, the designer chemist draws a flowsheet. This is naturally structured keeping production as an objective. But when we are interested in prevention of pollution, our priority is different and hence our flowsheet will be different. The old one needs to be restructured. Here the stress will be to measure waste rather than the product. Here the system boundary is not limited merely to a single unit, reactor by reactor, but it is holistic, covering the complex network. To begin with, we should have a qualitative understanding, for which the simplest tool is mass balance. The following checklist will help:

- Can the waste stream be eliminated with change in raw material?
- Will a change in process condition (temperature, pressure, reactant conditions, time, etc) reduce the waste generation?
- Will a change in process configuration reduce the waste generation?
- Can the waste serve as a raw material for another process?
- What would be the impact of each pollution prevention step on the entire process and on the finished product?

4.3.4 Case study: Specialty alcohol

Process: A batch of crude alcohol with acid residuals enters the wash kettle and is mixed with water, chemical scavenging agents and isopropyl alcohol. The mixture is agitated and then allowed to settle. The desired alcohol product separates from the wash and settles at the bottom of the kettle. The mixture is then drained from bottom of the kettle, with the help of a sight glass monitored by an operator, and sent to an accumulator tank. When the product layer has drained and the aqueous wash has started to exit the kettle, the operator diverts that flow to a sump for disposal.

The product layer in the accumulator tank is then returned to the wash kettle for a second wash again with water, scavenger and isopropyl alcohol. Again the mixture is agitated and then allowed to settle. The kettle is drained, with specialty alcohol product going to the accumulator tank. Again the operator diverts the aqueous wash to the wastewater sump for disposal. From the accumulator tank,

the specialty alcohol is filtered, drummed and shipped. (All this is visualised in the flowsheet at fig. 4.2.)

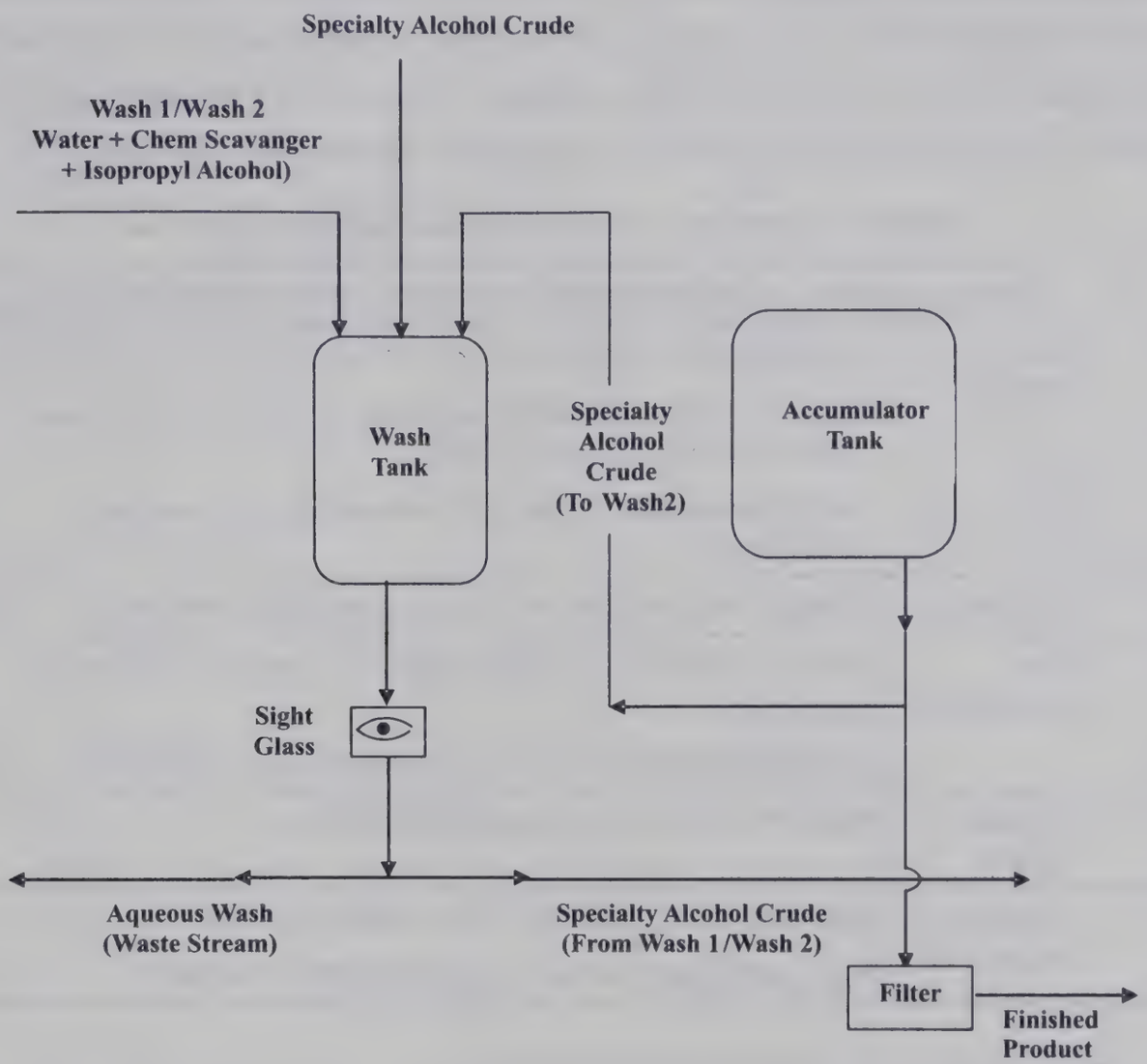


Fig. 4.2: A specialty alcohol wash process

Waste: The waste stream after process is typically composed of 93.6% water, 5.1% isopropyl alcohol, 0.7% specialty alcohol and 0.6% organic chemicals. Excluding water, the isopropyl alcohol accounts for 80% of the waste stream and 94% of the total organic contents. At present, the wash process produces 0.15 kg of total organic content in the waste stream for every kilo of specialty alcohol produced. This waste stream is sent to the on-site ETP for treatment and disposal. The cost associated with the waste stream includes (1) replacement cost of isopropyl alcohol and the chemical scavengers, (2) the yield loss represented by specialty alcohol component and (3) effluent treatment plant cost.

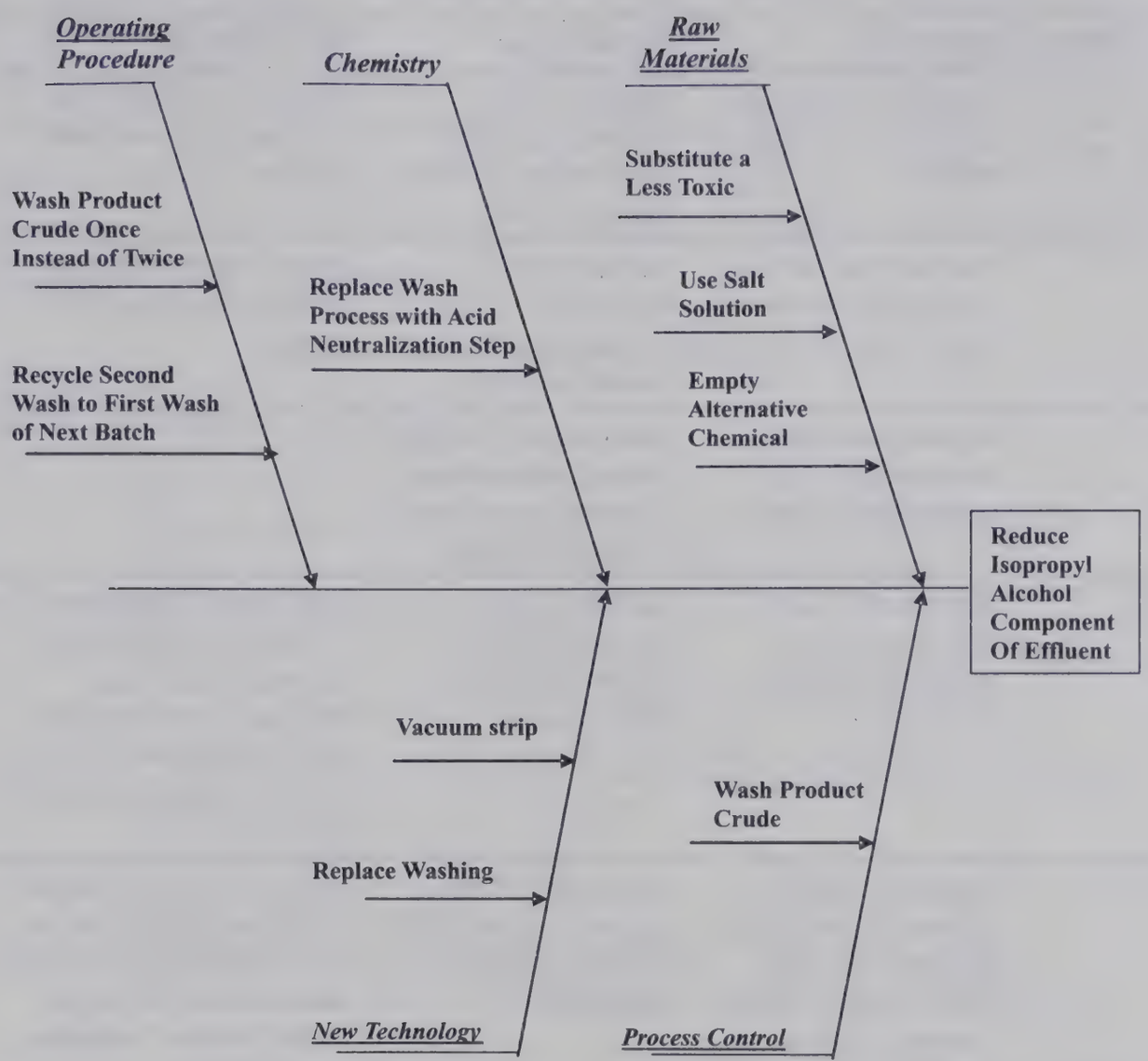
Minimisation: With this background we viewed the scheme for WM. For this purpose, a brainstorming session was conducted, and as many as nine options emerged: one from chemistry, two from new technologies, three from raw materials, one from process control and two options from operative procedures. These are tabulated below (table 7), and also shown in the option tree diagram in figure 4.3.

Table 7: Outcomes of brain-storming sessions

Nine outcomes of brain-storming sessions, with change in		
1	Raw materials	Substitute a less toxic solvent for isopropyl alcohol
2		Use salt solution instead of isopropyl alcohol, and also wash the product once instead of twice
3		Employ alternative chemistry to eliminate acid residual in crude product.
4	Chemistry	Replace washing process with acid neutralization step
5	New technology	Vacuum strip the isopropyl alcohol from wash and do recycling
6		Replace washing with alternative separation technology
7	Process control	Wash product crude at higher temperature.
8	Operating procedure	Wash product crude only once, instead of twice.
9		Recycle the second wash as first wash of next batch

Subsequent discussion revealed that

- Changes in reaction chemistry or separation technology were poorly defined (option No. 3 and 8), and could not be implemented without significant research. Capital expenditure would also be high and would need long period for development.
- Options 1 and 2 were to be considered last.
- Acid neutralisation (option 4) offered a complete source reduction of waste with little capital expenditure. It could also simultaneously meet all other process improvement goals. Hence it was selected.



NOTE: Process control can have sub branches, if there are two reactants or reactors, each having 2 or 3 options.

Fig 4.3: Option tree chart

Based on these discussions, all nine options were compared. Table 8 provides a ranked summary of WM options for the specialty alcohol wash process.

Decision: A step-by-step or sequential design procedure for pollution prevention was worked out based on the above preparatory drill. Reviewing the existing flowsheet became necessary. For working out a new flowsheet (waste oriented), choices of raw materials, catalysts, reactor design, separator design, level of energy integration would have to be considered which would lead to large number of possible flowsheets.

Table 8: Ranked summary of WM options for specialty alcohol

Option	Describe	Advantages	Disadvantages
8	Wash product crude only once, instead of twice.	Reduction of isopropyl alcohol component of waste stream by half	Would not attain other process improvement goals
9	Recycle the second wash as first wash of next batch	Reduction of isopropyl alcohol component of waste stream by half	Would not attain other process improvement goals
4	Replace washing process with acid neutralization step	Elimination of waste stream. Attainment of other process-improvement-goals	--
1	Substitute a less toxic solvent for isopropyl alcohol	Substitution of waste isopropyl alcohol with less toxic waste	Alternative solvent is undefined. Alternative solvent would pose disposal problem of its own. No real reduction in the amount of waste produced
2	Use salt solution instead of isopropyl alcohol, and also wash product once instead of twice	Reduction of total organic content load in waste stream by about 94%	Uncertainty whether salt facilitates separation as well as isopropyl alcohol does. Would not attain other process improvement goals
3	Employ alternative chemistry to eliminate acid residual in product crude.	Elimination of waste stream	Alternative chemistry is undefined. High research cost. High capital cost. Long implementation time.
5	Vacuum strip the isopropyl alcohol from wash and recycling	Elimination of isopropyl alcohol component of waste stream	Not a source reduction. High research cost. High capital cost. Long implementation time
6	Replace washing with alternative separation technology	Elimination of waste stream	Uncertain chance of success. High research cost. High capital cost. Long implementation time
7	Wash product crude at higher temperature	Elimination or reduction of isopropyl alcohol component of the waste stream	Uncertain chance of success. Would not attain other process improvement goals.

This framework offers a systematic approach to constructing a flowsheet that generates a minimum of waste. The advantage of this method is that it explicitly recognises that waste reduction cannot be relegated to the end of the design process. Rather, it must be integrated into all decision levels, right from beginning. Decisions are to be made at many design levels, to evaluate possible waste reduction strategies. This is indicated in table 9:

Table 9: Strategies for problem-solving

Level	Strategy for problem-solving
1	Input/output structure of the flowsheet 1. Problem caused by the reaction chemistry? – Change the chemistry 2. Problem caused by spent catalysts? – Regenerate the catalyst
2	Recycle structure of the flowsheet 1. Problem caused by adding reactor diluents to shift the product distribution or to shift the equilibrium conversion? – Change the diluent 2. Problem caused by adding reactor solvents? – Change the solvent
3	Specification of the separation system a. General structure: Phase splits. b. Vapour-recovery system 1. Problem caused by absorber solvents? – Change the solvent 2. Problem caused by regeneration of absorption beds? – Change the bed stripping agent 3. Problem with removing spent absorbents? – Change to absorption or condensation 4. Problem caused by the use of reactive absorbers to remove toxic materials? – Go on similar lines. c. Liquid-recovery system 1. Problem caused by stripping agents? – Change the agent 2. Problem by extraction solvents? – Change the solvent 3. Problem by crystallizer (recycle) and purge streams (almost pure water)? – Reuse the purge water elsewhere in the process 4. Problem by crystallizer purge streams (not almost pure water, as above) ? – Remove the contaminants and recycle the water or look for a different separation system. 5. Problem caused by reactive crystallization by-products? – Look for a different separation technique 6. Problem caused by spent absorbents? – Regenerate the absorbent d. Solid-recovery system 1. Problem caused by cake washing? – Same as for crystallizer, filter mother liquor streams.

4.3.5 Assembling information

Even before the brainstorming session described earlier begins, we have collected and compiled the relevant information. Thus we should already have some broad knowledge of the following in our possession, namely:

- What waste streams are generated here? What is their nature? How much?
- What is the proportion i.e. from which process, operation, reactor?
- Which of the wastes are non-hazardous? Which are hazardous? What ingredient makes them hazardous? Whether the latest legal definition alters their position?
- What are the corresponding input chemicals that make the waste hazardous?
- How much of that hazardous input chemical results in making the waste hazardous or non-recyclable?
- By comparing annual consumption and annual purchases, or by random sampling, how much escapes as fugitive discharges?
- How efficient is the process? How efficient is the equipment? How reliable is the calibration of the instrumentation?
- Is the recyclable waste getting mixed with the non-recyclable waste load? Is segregation uniformly practised?
- How much further scope for good house-keeping exists in various shops?

(At this stage, more specific information will be required from every shop section for WM assessment.) The relevant information and relevant sections to be sourced are in table 10:

Table 10: Assembling additional information

#	For aspect of	Information required
1	Design	Flow diagram Material application diagram, mass balance Piping and instrumentation diagram Equipment list, specifications, drawings, data sheets, operation and maintenance manuals Plot plan, arrangement drawings, and work flow diagram Civil and foundation drawings
2	Environment	Hazardous waste category and quantities authorized by SPCB. Whether manifest (colour-coded and hexaplicate) tallies? Air pollution emission inventories and waste assays for comparison with consent conditions. Periodical hazardous waste reports, in formats prescribed by the Act. Environmental audit report, statutory Environmental Statement Water pollution effluent sub-stream inventories and characterisation for comparison with consent conditions. Spill episodes/release prevention and countermeasure plan
3	Raw materials, additives and feeding	Unit-wise, reactor-wise, product-wise composition sheets regarding reactants, mother liquor, washing and work-up water and quantification MSDS assembled for all Batch sheets scenario Product and raw material inventory record Production schedule Operator data log
4	Economics	Waste treatment and disposal cost, for all aspects like sewage, effluent, air pollutants, hazardous solid waste and non-hazardous solid waste. Utility and raw material cost structure Operation and maintenance material and labour cost
5	Other	Environment policy statement Standard operation procedure Organization chart and line of command, present and needing modification

In a reactor, a number of items enter at feeding time and at separation/purification a number of items leave the reactor. For an in-depth waste management analysis (keeping in mind that for every item there is a possibility of recovery), table 11 will guide the WMO:

Table 11: T/T or T/month

Name of the Product.....,				
INPUT		**Name of unit operation/process (reactor-wise)**	**OUTGOING**	
Various columns	**Total**		**Various columns**	**Total**
New raw materials Last step's accumulated mass Solvents Catalyst Work-up chemical Water for washing Water for solution Any other		Reactor 1 (e.g., Azotization)	Mother liquor or as raw materials for the next step Spent solvents Spent catalyst Wastewater Scrubber water Hazardous solid waste Non-hazardous solid waste Gas Any other	
		Reactor 2 etc		
		Reactor 3. Purification.		
Total	...	Total	...	

'Mass in' will tally with the sum of 'mass out' and 'mass accumulated' (i.e. mother liquor, intermediate or product), and the mass accumulated will pass to next step.

The above table gives us reaction-wise or reactor-wise, the solid waste, air emissions and effluents. For every waste, a table of the following type (table 12) must be constructed as the next step i.e. tracking. This will enable us to identify waste reduction opportunities.

The table 12 clearly shows:

- the present waste streams (with individual volume and characteristics);
- the future possible waste streams after implementing changes (with individual volumes and characteristics);
- the present waste management practice;
- the future waste management practice, assuming possible changes in authorisation conditions.

Table 12: Waste tracking

Unit reaction in product	Waste description	Hazardous property	Quantity generated per batch converted to TPY	Management cost Rs /Yr	Possible minimisation method
Distillation/ amination / purification etc. (separate table for each step)	Organic acid	Flammable	..	...	Recycle
	Polymers	Caustic			Sale
	Spent catalyst	Acidic			Reuse
	Lab solvent	Ignitable			Fuel
	Acid catalyst	Corrosive			Administrative control

The exercise explained above is to be done both for existing method of production and also for proposed method for WM. The typical waste from plant operations may be now assembled as shown in table 13:

Table 13: Typical waste from plant operations

#	Plant operation/location/ function	Potential waste material
1	Material received at loading docks, incoming pipelines, receiving areas	Packaging materials, off-specification materials, damaged containers, inadvertent spills, transfer hose emptying
2	Raw material and product storage: tanks, tank-farm, warehouses, drum storage yard, bins, store rooms, shop-storage	Tank bottoms, off-specification and excess materials, spill residues, leaking pumps, valves, tanks and pipes, damaged containers, empty containers
3	Production shop, melting, curing, baking, distillation, washing, coating, formulation, reactions, separation, purification, drying, etc.	Wash water, rinse water, solvents, still bottoms, off-specification products, catalysts, empty containers, sweepings, duct work cleanout, additives, oil, filters, spill residue, excess materials, process solution dumps, leaking pipes, valves, hoses, tanks and process equipment
4	Laboratories	Reagents, off-specification chemicals, samples, empty sample and chemical containers
5	Maintenance shop	Solvents, cleaning agents, degreasing sludges, sand blasting wastes, caustics, scrap metals, oils, greases

6	Garages and fork-lift vehicle maintenance	Oils, filters, solvents, acids, caustics, cleaning bath sludges, batteries
7	Power house/boilers/co-generation plant	Fly ash, slag, tube clean-out materials, chemical additives, oil, empty containers, boiler blow-down, water treating chemicals wastes
8	Cooling towers	Chemical additives, empty containers, cooling tower bottom sediments, cooling tower blow-downs, fan tube oils.

4.3.6 Controlling factors

It is desirable that waste is controlled at generation stage itself, since prevention is always better than cure. Knowing the experiences of others who have achieved solutions after much trial and error (see table 14) will certainly help the reader design a superior WM programme.

Table 14: Experience in WR

#	Waste station	Waste causes	Design factors
1	Chemical reaction	Incomplete conversion, ineffective mixing or distribution, by-product formation, catalyst deactivation (maybe by poisoning or sintering). Improper separation, inadequate temperature or pressure control, inadequate mixing, poor feed flow/feed purity control.	Proper reactor design/ catalyst selection. Choice of process/ reaction conditions. Micro-processor.
2	Contact between water and organics	Condensate from steam jet ejectors. Presence of water as a reaction by-product. Use of water for product rinse. Equipment cleaning. Spill clean-up. Indiscriminate use of water for cleaning or washings.	Vacuum pumps instead of steam jet ejectors. Choice of process. Use of reboilers instead of steam stripping.
3	Equipment cleaning	Deposit formation. Use of filter aids. Use of chemical cleaners. Drainage prior to cleaning.	Production scheduling to reduce cleaning frequency. Design reactors or tanks wiper blades. Reduce cling. Equipment dedication.

4	Heat exchanger cleaning	Presence of deposit (process side) or scale (cooling water side). Use of chemical cleaners. Inadequate cooling water treatment. Excessive cooling water temperature.	Design for lower film temperature and high turbulence. Controls to prevent cooling water from overheating.
5	Metal parts cleaning	Disposal of spent solvents, spent cleaning solutions, or cleaning sludges. Indiscriminate use of solvent or water.	Choice between cold dip tank or vapour degreasing. Choice between solvent or aqueous cleaning solution.
6	Metal surface treatment	Drag-out. Disposal of spent treating solution. Poor rack maintenance. Excessive rinsing with water. Jobs with cavities, but without draining holes. Fast removal of work-piece job.	Countercurrent rinsing. Fog rinsing. Drag-out collection tanks or trays.
7		Disposal of non-reusable raw materials or off-specification products.	Stale and obsolete raw materials. Products required to be discarded due to contamination. Improper reactants control. Inadequate pre-cleaning of equipment or work-piece. Runaway, temperature or pressure excursions. Poor operator training/supervision. Inadequate quality control/production planning/inventory control of feedstock. Use of automation. Maximise dedication of equipment to a single function.
8	Clean-up of spills and leaks	Manual material transfer and handling operations. Leaking pump seals. Leaking flange gaskets. Inadequate maintenance. Poor operator training. Excessive use of water in cleaning.	Choice of gasketing materials. Choice of seals. Use of welded or seal-welded construction.

Before finally implementing the WM programme, the area should be photographed and checked for signs of previous leaks, spills, overflows.

4.3.7 Experience – A case study

Table 15 provides a checklist of steps taken by an industry while designing a WM programme:

Table 15: Checklist for a WM programme

Step	Action	Nature of Activity
One	Identify the problem waste that is to be minimised. First, prepare a full list, and then shortlist it (by prioritization technique)	Refer to table A, below.
Two	Make a general list of technologies, including the vendors offering them in your area.	Description of all technologies is given in chapter 3. Refer to table B, below.
Three	Shortlist the technology found to be suitable.	Refer to table C, below
Four	Select best preferred 2 or 3 options from table C, for further scrutiny	The scrutiny is to check the pretreatment requirement of the waste before application of the said technology. Less pretreatment, the better. Refer to table D, below
Five	Every activity creates residue waste. Minimum secondary residual waste, the better. Hence make scrutiny of the 2 or 3 options on this count.	This scrutiny is to check the complexity of residue treatment required for the waste. Least weight, volume, toxicity, complexity of post-treatment, the better. Refer to table E, below
Six	Finalise. 1. The waste 2. The technology 3. The pretreatment 4. The post-treatment.	Complete the design. Fill in the information gaps Make laboratory/bench/pilot study Implement. Success? Go ahead. Part failure? Make appropriate modifications. Total failure? Select another option.

Table A: Examples of constituents within waste group

Legend – constituents	
1. Halogenated volatiles	9. Volatile metals
2. Halogenated semi-volatiles	10. Non-volatile metals
3. Non-halogenated volatiles	11. Asbestos
4. Non-halogenated semi-volatiles	12. Radio-active materials
5. PCBs	13. Inorganic corrosive
6. Pesticides	14. Inorganic cyanide
7. Organic cyanides	15. Oxidizers
8. Organic corrosive	16. Reducers

Table B: Examples of modern technologies available for attempting waste recovery

Legend – technology	
A. Fluidized bed incinerator	H. *In-situ* chemical treatment
B. Rotary kiln incinerator	I. Glycolate dechlorination
C. Infra-red thermal treatment	J. Stabilisation/solidification
D. Wet air oxidation	K. Chemical reduction, oxidation
E. Pyrolysis incineration	L. *In-situ* vitrification
F. Vitrification	M. Bio-degradation
G. Chemical extraction	N. *In-situ* bio-degradation

Table C: Technology selection guide for waste group

Technology → Waste	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	P	D	D	P	P	P	P	N	P	P	P	P	P	P
2	P	D	D	P	P	P	D	N	P	P	P	P	P	P
3	P	D	D	P	P	P	P	N	N	P	P	P	P	P
4	P	D	D	P	P	P	D	N	N	P	P	P	P	P
5	P	D	D	P	P	P	D	N	P	P	P	P	P	P
6	P	D	P	P	P	P	P	N	P	P	P	P	P	P
7	P	D	P	P	P	P	P	P	N	P	D	P	P	P
8	P	D	P	P	P	P	P	P	N	P	N	P	X	X
9	X	X	X	N	N	X	N	N	N	D	P	P	X	X
10	N	N	N	N	N	P	N	N	N	D	P	P	X	X
11	N	N	N	N	P	D	N	N	N	D	N	N	X	X
12	N	N	N	N	N	P	N	N	N	D	N	D	X	X
13	N	N	N	P	P	P	N	P	N	D	N	P	X	X
14	N	N	N	P	P	P	N	P	N	D	D	P	X	X
15	N	N	N	N	P	P	X	P	N	P	P	P	X	X
16	N	N	N	N	N	N	X	P	N	P	P	P	X	X

D = Demonstrated effectiveness
P = Potential effectiveness
N = Not effective
X = Adverse to process or environment
The numbers given to rows correspond to the wastes listed in table A.
The letters given to columns correspond to technologies listed in table B.

Table D: Pretreatment for solids, sludges, slurry, liquors or solutions.

#	Problem	Solution
1	Excessive water contents	A. Evaporation – Where sludge is mixed with oil, first form a slurry and then send to multiple effect evaporators. B. Filter press – Pumped into cavities formed by series of plates, covered by filter cloth. Sludge solids remain on cloth. C. Belt filter – Sludge drops on perforated belt, where gravity drainage takes place. Thickened sludge is pressed in between series of rollers to produce dry cake. D. Vacuum filter – Fed on rotating perforated drum with internal vacuum, extracts liquid phase. E. Centrifuge – Sludge fed through central pipe, sprays in rotating bowl, solids to bottom hopper, removed by screw. F. Drying – Rotating dryer, flash drying, or sand beds G. Gravity thickening – Taking advantage of different specific gravities, solids migrate to bottom, removed by scrapers. H. Chemicals addition – Compounds may be added to physically or chemically bound water.
2	Excessive sludge viscosity	Slurry status. Addition of water or solvent or dispersants.
3	Extreme pH	Add lime or sulphuric acid or similar reagent.
4	Oversized material	Homogenising. Vibratory screens, static screens, hammer mill, crusher, shredder, cyclone, tumbling mill, grizzlies (parallel bar screen).

(Note: This is only an indicative list)

Table E: Secondary residual waste management

Residues	Technology it arises from	Contaminants	Potential management
Treated ash	Fluidized bed incinerator Rotary kiln incinerator Infra-red thermal treatment	Metals	Stabilization/vitrification
Ash, afterburner	Low temperature thermal stripping	Volatile metal	Stabilization/vitrification
Solid ash	Wet air oxidation	Metal oxides, insoluble salts	Stabilization, solidification, vitrification
Solids	Chemical extraction	Metals, trace organics	Stabilization, solidification, vitrification
Spent activated carbon	Low temperature thermal stripping, air and water pollution control	Volatile organics	Incineration, thermal regeneration, wet air oxidation, steam stripping with water treatment, bio-degradation

Fly ash	ESP, bag house, cyclone	Volatile metals	Stabilization/solidification/ recycled to primary thermal unit, reuse of ash
Aquatic effluent	Chemical extraction	Trace organics	Biological treatment/ carbon adsorption
Aquatic effluent	Wet air oxidation	Carboxylic acids and other carbonyl group compounds	Biological treatment/ carbon adsorption
Aquatic effluent	Wet air oxidation	Low molecular weight organ-ics such as acetaldehyde, acetone, methanol	Photo-oxidation, chemical oxidation
Organic effluent	Solvent extraction	Organic (Non-PCB)	Recycle, reuse as fuel
Organic effluent	Solvent extraction	Organics mixed with PCB	Incineration

If the waste is not excessive, it can also be taken care of by existing standard management practices, i.e., incineration, secured landfill and ETP.

4.4 Evaluation

The WM programme that is finalised also needs to be evaluated. The EPA at Illinois Information Centre has listed some significant attributes (table 16) one needs to evaluate:

Table 16: Evaluation of a WM programme

#	Project element	Evaluation criteria
1	Management support	Statement of support Approval of project Providing ideas/input Praise and publicity of successes
2	Team aspects/programme initiation	Employee enthusiasm and participation Using skills from training Supporting projects Providing ideas
3	Understanding process	Processes characterized Flow diagram developed All wastes and sources identified Waste accounting system implemented

4	Project implementation	Projects completed within budget Projects completed on schedule Waste reduction achieved Cost savings attained Raw material saving achieved Product quality improved Worker safety improved Cost allocation system implemented
5	Continuing the programme	Follow-up and review procedures established Employees kept informed and involved Pollution prevention team composition rotated

(Source: "Pollution Prevention: A Guide to Program Implementation." Illinois Hazardous Waste Reduction Information Centre, 1993)

After implementing the WM programme, repeat the exercise whenever there are new situations. The findings of this exercise should be compared with the earlier scenario. This is called tracking the WM programme.

4.5 Approaches

So far, we have attempted to make a list of all the possible unit operations for all the products reactor-wise. We have also suggested a number of alternatives for each waste. It is, however, clear that no industry can undertake minimisation of all the wastes at the same time, nor can all the options for the same waste be implemented at the same time. One has to prioritise. There are several ways of deciding priorities.

One approach is to look at the wastes and try to decide which one to take up first.

1. The most precious waste: It may give better monetary returns for the reclamation efforts that are made: for instance, gold or silver plating waste.

2. The most voluminous waste: it may offer economies of scale.

3. The easiest waste: It may give sure success, which will be appreciated by the authorities.

4. The most reusable waste: It may give better monetary returns: for example, solvent extracted and reused in the same reactor.

5. The most hazardous waste: It will bring necessary relief to people, the environment and property.

6. The most mal-odourous waste: It will enable industry to develop harmonious relations with people in the vicinity.

7. The most repetitive utility waste: It may allow a continuous uninterrupted running and better monetary returns for the efforts made: for example, solvent extraction.

Another approach is to prioritise in terms of efficiency of technology.

1. The most preferred option will be the one that will decrease the generation of hazardous waste at the source itself (source reduction).

2. The next preferred option will be the one that will reclaim such materials that have a positive recyclable value (reuse, recovery, recycling).

3. The next preferred option will be one that will treat the contaminants found in various plant discharges and emissions and make the environment congenial, but will not reclaim and recycle the waste.

4. The least preferred option is the one that stores, transports or disposes the HW made in a manner that avoids leaks, fires and spills (storage and disposal).

One factor that must be kept in mind is that in case the technology has potential side-effects, it is better to select one that will create less problems even if the WM is reduced. To enable such a negative comparison, marking is suggested, as follows (table 17):

Table 17: Marking

#	Attribute	Negative marks			
		0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
1	Collectively thinking, refer the MSIHC Rules, 1989, as amended in 2000, for table of regulatory quantity.	> 100 T	50-100 T	1-500 T	1 kg – 1T
2	Collectively thinking, ratio of reactant input to reactant theoretical need	1 : 1	1 : 5	1 : 7.5	>10

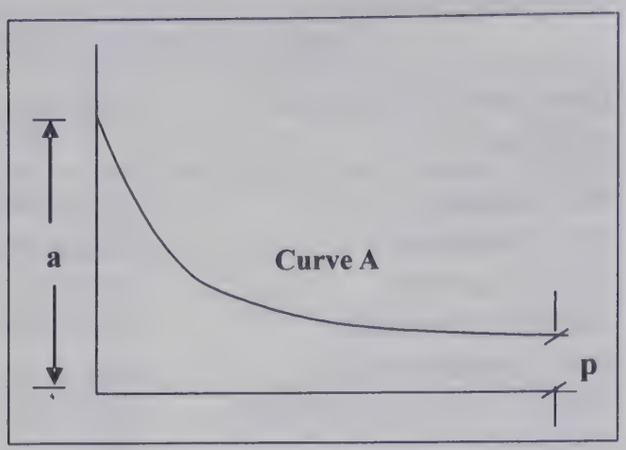
3	Collectively thinking, raw material solubility in water	No	Sparingly	Soluble	Reacts
4	Collectively thinking, raw material viscosity	Low	Moderate	High	Very High
5	Collectively thinking, raw material toxicity LD50 rat oral mg/kg	>200	50-200	5-50	<5
6	Reaction pressure	Room	Negative	2 Atm	>2 Atm
7	Reaction temperature	Room	> Room	60 °C	>100 °C
8	Reaction exothermic	No	Low	Moderate	High
9	Reaction rate	Slow	Moderate	High	Fast
10	Mixing nature	Thor-ough	Moderate	Low	Pockets
11	Reaction direction	Uni	Side, 1 step	Side, chain	Complex

4.5.2 Costs

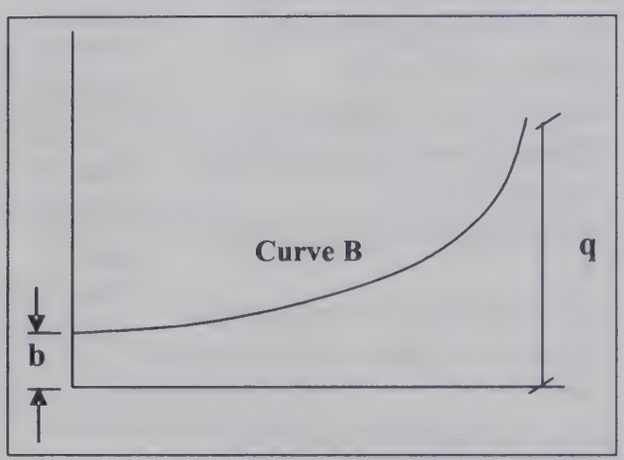
There is a similarity between expenditure on the production process and expenditure on the WM recovery process. For an efficient production process, efficient heating is necessary. For efficient heating, optimum insulation thickness is necessary. The thicker the insulation, the less is the heat loss and less the cost. This is depicted by a series of conceptual graphs in figure 4.4.

Whatever is stated in fig 4.4 about heat loss is equally applicable to raw material loss. If the cost of fresh raw materials is to be saved, more waste recovery effort is the answer. In the absence of recovery, the cost of fresh raw materials will be high. The more the recovery, the more is the reclaimed-recycled material and the less is the cost of fresh raw materials. This position is similar to what is reflected in the above graphs, making progressive raw material recovery efforts synonymous to improving insulation so that cost of heating becomes synonymous with raw material cost. Thus the same curve conceptually shows that the greater the recovery efforts, the less is the raw material loss and the cost of raw material.

This is a Heat Cost-Insulation Thickness graph. Shown on Y axis is the cost of heat loss in rupees per annum, and on X axis is the insulation thickness. The curve conceptually shows that thicker the insulation, expenditure cost of heat loss in rupees on Y-axis becomes less. (This is denoted in the range of 'p' to 'a', and the curve is marked as Curve 'A)



This is an Insulation Cost-Insulation Thickness graph. Shown on Y axis is the expenditure cost of installing insulation in rupees per annum, and on X axis is the insulation thickness. The curve conceptually shows that thicker the insulation, expenditure cost of insulation in rupees on Y-axis increases. (This is denoted in the range of 'q' to 'b', and the curve is marked as Curve 'B') (Installing the insulation involves cost. This capital cost will have two components, one fixed cost for erection and another for insulation, depending on its insulation. Taking into consideration the life of insulation, this capital cost can be converted and expressed as cost per annum.)



Curve A shows the variable cost of heat loss and Curve B shows the variable cost of insulation. When one is the lowest, the other is the highest. How can optimum expenditure be found? For that, Curves A and B must be combined. This is done here. Curve C emerges. Here Y axis becomes 'a + b' and 'p + q', as maximum point for resultant Curve C. The minimum becomes 'c'. This means the cost 'c/2' each can be debited to expenditure on heat and expenditure on insulation.

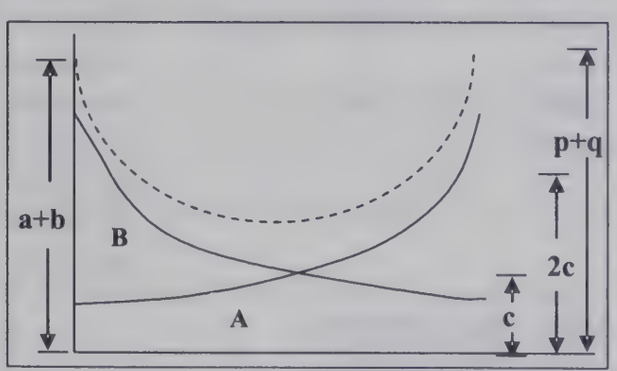


Fig. 4.4 Similarities in expenditures for production and WM recovery process

Table 18: Various cost attributes related to

Raw material and substances	Waste generation	Waste handling
Purchasing: Cost and taxes Safety training MSDS compilation Safety equipment Extra insurance premium Labour	**Air/water emissions/effluents:** Permits and control Measurements, estimates Reporting Fees Workers' health monitoring Sewer discharge fees NPDES permits (consents) W.Q. monitoring Sampling training Pretreatment equipment Pre-treatment system operation	**Waste storage:** Storage permits Special storage facility Spill containment equipment Emergency response planning Safety training Storage area inspection
Storage and Inventory: Special storage facilities Safety equipment Storage area inspection Storage container labeling Safety training Emergency response planning Spill containment equipment Loss from spill, evaporation Labour Documentation-reporting		**On-site treatment/recycling:** Capital and operating cost Depreciation Utilities Operators' training Safety equipment Emergency response planning Permits Inspection and monitoring Insurance
In-process use: Safety training Safety equipment Containment facilities, equipment Clean-up supplies Labour	**Solid waste collection:** Safety training Safety equipment Collection supplies Container labels Container labeling Record keeping In-house fleet maintenance	**Disposal:** Sewer fees Container manifesting Disposal vendor fees Preparation for transportation Transportation Insurance and liabilities Monitoring of disposal site.
Lost raw materials: Labour for handling Equipment for clean-up Reporting		

The analogy, when taken further, tells us that the more sophisticated the recovery gadget, the capital cost may be more, but recovery too will be greater, leading to overall reduction in costs. One more point worth noting is that where capital cost is more, the operating cost is low and vice versa.

For determining costs, having the dimensions of the gadget is necessary. Experience tells us that unless laboratory scale, bench

scale or pilot scale trials are done, going directly to full scale extrapolation is costly (both in terms of time and money).

A Washington State Department of Ecology document titled 'Pollution Prevention Planning' states that the waste cost depends on raw materials, waste and waste handling; each of these in turn have several attributes. These are tabulated in table 18.

This section will become useful for preparing proposals and for obtaining support from higher management for implementation of a WM programme. Once it is commissioned, industry will enjoy the comfort of good public relations and freedom from litigation.

4.5.3 Ranking

Ranking is comparison of many options, giving marks to each depending on the degree of satisfaction received in relation to eight aspects listed in table 19, preferably in the order of preference given in the same table:

Table 19: Aspects for ranking

1	Regulatory compliance	5	Effect on product quality
2	Probability of success	6	Potential by-product recovery
3	Waste reduction potential	7	Potential reusable recovery
4	Safety	8	Ease of implementation

Marks may be given (out of 10) for each attribute and weightage fixed to each attribute. This will give the sub-rating and the sum total will give the total marks for each method. The total marks for each option can be compared and ranking given.

Had there been only two attributes, namely technological and economic feasibility, perhaps the rating would have been simpler (table 20):

Table 20: Rating on technological or economic grounds

Rating		Technological feasibility		
		High	Medium	Low
Need or economic feasibility	High	10	7	5
	Medium	7	5	3
	Low	5	3	1

WM is not so simple, but a case study will help us to understand it better. An industry was desirous of implementing a WM programme. Four optional measures were available. These were:

Option A: To replace the existing reactor and install a fresh one – technically a very sound proposal.

Option B: To increase column pressure – a via media, technically workable, but giving lesser recovery.

Option C: To generate less waste by making less purification, thereby lowering the product quality.

Option D: To implement good operating practice, for e.g. training, incentives, close supervision, etc. without modification.

Table 21: Rating marks

#	Attribute	Allot marks			Allot weightage
		0 to 5, if	5, if	5 to 10, if	
1	Safety	Less safe, more risk	Same as existing	Safer, less risk	10
2	Capital cost	High or very high	Reasonable	Low or very low	10
3	Ease of implementation	Difficulties	Reasonable	Easy to surmount	8 (Note 1)
4	Probability of success	Some eventualities involved	Same as existing	High	10
5	Effect on product quality	Compromised quality	Same as existing	Better effect	6 (Note 2)
6	WM potential	Reduction in some, but increase in some volume, weight or toxicity	Same as existing	Reduction in all volume, weight and toxicity	10

Note 1: Less weightage, as this is a one-time operation
Note 2: Less weightage, as main customers have already agreed.

The WMO selected six attributes and assigned weightages to each. For giving individual marks to the 6 x 4 matrix, a rating conception was prepared.

Rating marks out of ten were as in table 21.

When equipped with this background work, table 22 was prepared for all the four options A to D, with weighted sum rating and ranking technique:

Table 22: Criteria for ranking options

#	Criteria	Weight-age	Option A Replace reactor		Option B Increase column pressure		Option C Lower the produce quality		Option D Implement good operating practice	
		W	R	R x W	R	R x W	R	R x W	R	R x W
1	Safety	10	10	100	4	40	8	80	8	80
2	Capital cost	10	0	0	8	80	10	100	10	100
3	Ease of implementation	8	2	16	7	56	10	80	9	72
4	Probability of success	10	6	60	4	40	8	80	8	80
5	Effect on quality	6	10	60	6	36	6	30	6	36
6	WR potential	10	8	80	2	20	5	50	4	40
7	Final sum of R x W	--		316		272		426		408
8	Ranking	--		3		4		1		2

The authorities are desirous of encouraging industry to go for WM and recycling, and have provided one incentive: an industry is not required to seek fresh environmental site clearance for expansion, if the pollution load is not proposed to be increased.

4.6 Plugging Failure Points

4.6.1 Sampling

We get waste and off-specification products due to runaway production reactions. While reclaiming this waste, if we again face a runaway reaction, how do we hope to end the vicious cycle? For breaking this cycle, it is essential to have an ability to perform measurements at the production and reclamation stages. Sampling helps at regulating hazardous waste and plugging failure points.

There are different ways of sample collection. These are collated in table 23:

Table 23: Different types of sampling

#	Type of sampling	Nature of sampling
1	Simple random sampling	Waste heterogeneous and no information on chemical properties or source available.
2	Stratified random sampling	If some information is available, divide the lot and in each lot take simpler random sampling.
3	Systemic random sampling	As in the simple random sampling, repeat at fixed distance, depth or time period.
4	Authentic sampling	When the person collecting the sample is knowledgeable.
5	Composite sampling	Combines several random samples (1 to 3) as above
6	Sub-sampling	Splitting the random/composite sample into many pieces (1 to 3 and 5)

Sampling tools are:

1. For water/watery slurry/sludge from drums, tanks, ponds, lagoons, pits: dipper, weighted bottle sampler, tap sampler.

2. For solid or sludge from drums, tanks, ponds, lagoons, pits: grain sampler, auger, trowel (scoop) shovel.

3. Ground water from leachate seeps or wells. Can be grab or composite.

4. Biological sample for bio-assay or diversity index.

5. Gas in landfill: by drive-in piezometer sampling, analysed by GC/MS or emission spectroscopy.

4.6.2 Estimation

Sampling and estimation must be done for hazardous characteristics like ignitability, corrosivity, reactivity and toxicity. For toxicity, leaching test is prescribed. Leaching test is of two types:

1. Extraction procedure (EP) test.

2. Toxicity characterisation leaching procedure (TCLP) test. For EP test, extraction is done with 0.5 N acetic acid at pH 5 for 24 hours. The result is analysed for eight element parameters and six organic compound pesticides. For the TCLP test,

- the leaching media is 0.1 N acetic acid solution (pH 2.9) for moderate to high alkaline waste and 0.1 N acetate buffer (pH 4.9) for other wastes;
- for liquid/solid separation 0.6-0.8 micrometer glass fiber filler filtration to 50 psi; and
- extraction time is 18 hours.

TCLP reasonable levels are expressed as mg/lit and have a background assumption of 100 times dilution by ground water in a well located at 150 metre down-gradient.

Other test details are described in brief in table 24.

Table 24: Test details

Ignitable	Flash point 60 °C by Pensky Marten method or Sea Flash method. Close cup method
Corrosive	Where pH <2 or > 12.5 or 0.250 in/year on steel
Reactivity	Material causing generation of harmful vapours or fumes that can present danger to human health or environment; which reacts violently with water; or has the ability to explode without detonation. Reactivity is construed accordingly.
Toxicity	Through EP sample. Maximum concentration in mg/lit given as arsenic 5/barium 100/cadmium 1/chromium 5/lead 5/mercury 0.2/selenium 1/silver 5/endrin 0.02/lindane 0.4/methoxychlor 10/ toxaphene 0.5/ 2-4-D acid 10/ 2-4-5 TP silvex 1.0, benzene 0.5, chlorobenzene 100,

In future, the sample collection and analysis will have to be more detailed. For example:

- Field measurement of organic compounds by GC.
- Robotocised analytical technique.
- Application of infra-red spectroscopy to hazardous waste X-ray fluorescence field method for screening of inorganic contaminants at HW sites.
- Application of X-ray fluorescence spectrometry to analyse hazardous waste.
- Bioassay to characterise genotoxicity of hazardous waste and effluents.
- Plant test system for detection of genetic hazards from environment chemicals.

4.6.3 Control by microprocessors

Sophisticated operations control by utilising microprocessors are being developed to plug failure points.

A microprocessor will control temperature and keep correct environment inside a reactor. This is extremely advantageous for situations where:

- The reaction is considerably exothermic.
- The reaction is mildly exothermic, but is over an extended period of time.
- The reaction is exothermic, but dies down before addition of further reagents (and needs adjustment).
- The reaction is exothermic, it might affect crystal size and filtration-separation; it might take more time for filtration and end in less yields.

A microprocessor will control the pH and keep the correct environment inside a reactor. This is advantageous in situations where:

- pH control is necessary at initiation of reaction, but changes are to be monitored and controlled to avoid hydrolysis and unwanted by-products.
- Alkali addition is controlled (quantity and rate of addition) by noting pH and temperature simultaneously.
- Acid is generated as a by-product, and if not neutralised inside the reactor will degrade the product.
- pH control for precipitation of desired material and help in separation of isomers having different pKa values is required.

Microprocessors can examine the suitability of a catalyst, optimise design and compare the behaviour of two or more competing catalysts.

5

IMPLEMENTING THE WM PROGRAMME

5.1 Training

5.1.1 Objectives

For successful implementation of the WM programme, it is necessary that all the people undertaking the programme are properly trained. Training includes refreshing the knowledge of those who are to be associated with the programme. Training brings uniformity of approach, predictable behaviour and the possibility of common errors getting eliminated.

The objective of a training programme is to (1) minimise occupational health hazards and errors; (2) to maximise safety; and (3) to instill good operating practices.

Commensurate with the above, a training programme will have as its objective the goal of reaching zero discharge waste, loss prevention at every step, methods for checking environmental obligations, awareness of risk-points, damage control and safety during normal operations.

5.1.2 Syllabus

Syllabus writing is one of the major responsibilities of the WMO. As the training will be for different categories of personnel, specific syllabus will have to be drawn and reading material prepared for each course.

A model training programme is sketched below, though the degree of depth can be varied. It is better to prepare reading material in the local languages and to distribute it in advance.

1. Discuss the need for pollution control and WM in particular. Give episodes. Inform what happens if WM is not done. Discuss LULU ('Locally Unaccepted Land Use') and public relations.

2. Explain environmental policy and management commitment.

3. Explain terminology and definitions, both technical and those used in common parlance, in simple terms.

4. Explain the provisions of laws, both environmental and criminal, in simple terms.

5. Demonstrate how basics work, starting from good housekeeping, arresting fugitives, preventive and predictive maintenance and reporting abnormalities in time.

6. Collect their ideas for WR, and then explain the industry's proposal.

7. Impart understanding of MSDS, properties, first-aid, medical relief.

8. Explain safety aspects, routine and accidental risks, evacuation and damage control.

9. Prepare formats for their shift-log and documentation.

5.2 Raw Materials Control

Raw material is the main cause of adverse environmental impacts. Air pollution like stratosphere ozone depletion, low level ozone and fog, emission of VOC, global warming, acid rains, etc., are no longer a distant possibility, they are here and now. Our own incinerator emissions (like oxides of nitrogen, SO_2, CO, metals, acid gases and toxic dioxins) may as well add to it, unless we review our raw materials.

It is worthwhile switching towards less hazardous raw material for many reasons: one, it lowers the risk to workers in the shop, office and colony; two, it produces less hazardous waste, in turn reducing the risk to transporter, environment and people; and three, it makes waste recovery easier. The search for raw materials is a continuous one as new materials are coming into the market every day, some with less toxicity.

5.2.1 Characteristics

Every raw material has characteristics of its own. When we wish to compare the present raw material with another, the characteristics of alternative material must be known in advance. Comparison can then be done on the basis of contents of MSDS and on basis of legal definition of hazardous material. The following logic (table 1) will have to be applied for selection of every potential raw material:

Table 1: Logic for selection

Q-No.	Question	Supplier response
1	Has the supplier provided the relevant MSDS and is not hiding behind 'trade secret'?	Y Positive
2	Is the flash point of the material > 140 ^{0}F ?	Y Positive
3	Does the material give off flammable vapour at > 65.5 ^{0}C, at open cup test?	Y Positive
4	Does the material not show high toxicity, ozone depleting nature, reactivity as with violent reaction with water, or liberating VOC?	Y Positive
5	Is the vendor amicable and willing to supply JIT (Just-In-Time), thus avoiding huge stock pile-up. Also is vendor willing to take back the surplus unused old material?	Y Positive
		Accept the material (*)

(*) Accept the raw material where response is positive, especially for Q-1,2 and 5, and accept if no other raw material is available answering Y to Q-3 and 4.

Raw material change is contemplated mainly to replace hazardous chemical with less hazardous or non-hazardous chemicals. Even if the replacing chemical is costlier, it may still be acceptable as its use may save on the ever-increasing cost and liability on resultant hazardous waste treatment and disposal (cradle to grave responsibility). Selection of purer raw material may look costlier in the beginning but may later prove to be economical with more yield, better conversion, no runaway reactions, less hazardous waste and less disposal cost.

Raw material change may also help with workers' health, product quality, ease of process operation, less inventory lock-up, production cost and manageable waste. A pilot scale, trial scale and phasing, will be the logical progressive steps. Such steps will pro-

vide an opportunity to check whether the change gives rise to cross pollution. There are numerous examples of waste reduction through raw material change as shown in table 2:

Table 2: Changes in technique

Industry engaged in	Material change in technique
Small appliances	Lubricant compatible with next process step is selected, avoiding wastage.
Printing	Substituted water based ink for solvent-based ink
Textiles processing	Reduced phosphate-containing chemicals, to avoid eutrophication
Engineering	Tried ultra-violate light instead of biocides in cooling water (though not continued)
Air conditioners	Replaced solvent-containing adhesives with water based products
Electronic components	Replaced water based film developing system with a dry system Replaced cyanide-cadmium plating bath with a non-cyanide bath
Ink making	Removed cobalt, cadmium from product
Plumbing fixtures	Replaced hexavalent chrome-plating bath with a low-concentration trivalent chrome-plating bath
Pharmaceuticals	Replaced solvent-based tablet-coating process with a water-based process.

5.2.2 Stock reduction

A large quantity of stock is another problem area, whether the stock is in the form of raw material, intermediate product, mother liquor, by-product, final product or waste.

Inventory management for stock therefore deserves careful attention. Examining the need for all kinds of stock is necessary during periodical stock-taking. On a printed format, write your decision as to whether a particular material is in excess, whether any part of it has crossed its expiry date, whether this is no longer used, and whether it is to be disposed of.

Reducing the stock is a complicated job. Inventory management at the purchase stage is more advisable. Purchase should be in small doses rather than bulk. Bulk may seem like a 'good deal', but it is not so if only one drum is needed. At the same time, the container must be of proper size. If too small, a number of empty cans are left

in our lap. Greater number means collectively more residual material left behind. Again, if the containers are too big, it is wasteful where use is not continuous, and its shelf life ends. Empty containers are also a problem. It will be good if the empty cans can be returned to the vendor or he can refill the containers. It is also preferable if the packing is such that the bags are soluble along with the raw material in mixer/reactor.

If raw material is found to be in excess or surplus, efforts are needed to consume them by arranging a production re-schedule either in the plant or in other branches of the company. If the supplier can buy back the material, it will be a good solution. If he can give a list of addresses of other industries needing this chemical, that too is a good solution. Avoid accepting wrong, off-specification or defective raw material in the first place. If this happens, then it becomes more complex to get rid of the excessive inventory.

Stock should preferably be on 'Ship-Shop-Ship' basis, i.e., raw material is shipped in to the industry in small quantities, it is unloaded directly in the manufacturing reactor or in the shop, and the reactor output product filled in package goes out shipped. Conceptually no storage is involved, in or out. This concept of 'Ship-Shop-Ship' is also described by some as 'Just-in-time'. It will also be a good approach to procure intermediate material (as raw material) and proceed further, instead of starting from the beginning. This outsourcing avoids stocking a long list of the initial chain of raw materials.

Check the efficiency of the procurement department (table 3):

Table 3: Checking efficiency of procurement department

Quantity used is	Quantity stored is	Manager is
Same as current	Same as current luxurious level	Average
Same as current	Reduced from current luxurious level	Good
Reduced from current	Much reduced from current level	Very good

If unused material is stored for prolonged periods, then the storage capacity is unavailable for useful material, disposal poses problems, capital is locked, fire risk becomes high, expiry date comes nearer, dampness spoils the value, weight is lost or gained, either way disturbing the stoichiometry and reaction kinetics, hence overall, the raw material becomes costly.

Here are some tips from experienced chemical engineers:

- Choosing a raw material which is directly supplied by the supplier avoids delays at intermediate depots and corresponding staleness and storage loading-unloading losses.
- The cost of appointing a person dedicated to examine raw material stocks and possible changes will be negligible compared with the thousands saved in production costs.
- Persons trained to read MSDS showed improvement in their handling of toxic materials.
- Reducing the inventory allowed the industry to breathe freely, as it reduced applicability of MSIHC Rules, 1989 (Manufacture, Storage and Import of Hazardous Chemical Rules) as regards greater responsibility applying to stocks exceeding the regulatory quantity.
- Dedicating one person to look after simple supervisory actions such as calibrating the weighing scale, welding the holes in hand-carts, leveling the internal road, collecting the spills, etc., justifies the expense.

Table 4: Potential sources of process material losses

Area	Source of loss
Loading	Leaking fill hose or fill line connections Draining of fill lines between filling Punctured, leaking or rusting containers Leaking valves, piping and pumps
Storage	Overfilling of tanks Improper or malfunctioning overflow alarms Punctured, leaking or rusted containers Leaking transfer pumps, valves and pipes Inadequate diking or open drain valve Improper material transfer procedures Lack of regular inspection Lack of training programme
Shop	Leaking process tanks Improperly operated and maintained process equipment Leaking valves, pipes and pumps Overflow of process tanks, improper overflow controls Leaks and spills during material transfer Inadequate diking Open drains Equipment and tank cleaning Off-specification raw materials Off-specification or discarded products

Table 4 above pin-points the potential sources of process material loss.

Table 5: Summary of MSDS information

Sec.	Heading	Information	Environmental significance
I	Material identification	Name, trade name, chemical name. Also known as, supplier's names, formula and where used.	To know the alibi, the alias, whom to contact in emergency, who may take back the surplus.
II	Hazard data	Ingredients, its concentration, CAS (Chemical Abstract Service) or UN number, LD 50 and LC 50 toxicity.	Which ingredients contribute to its hazardous nature, level of toxicity.
III	Physical data	State, odour, colour, specific gravity, evaporation rate, boiling/freezing point, pH, solubility	Whether it is likely to increase water pollution as SS, TDS, COD, settleability, need of neutralization, aesthetic nuisance value.
IV	Fire-explosion data	Potential for inflammability, any special procedure to extinguish, explosive limits (lower and higher by volume), auto-ignition temperature, combustion products.	Precautions for storage, unloading, temperature control, risks in recovery, planning for possible hazards to environs due to combustible products
V	Reactivity data	Stability, compatibility, decomposition products, conditions enhancing reactivity. Storage precautions (temperature, pressure, distances).	Planning for possible hazard to neighbours by decomposition products.
VI	Toxicological data	Mode of entry, effects of acute and chronic exposure, special effects like irritant, sensitization, cancer-producing, reproductive mutagenicity, permissible value.	Precautions to store and keep away from, risks in recovery.
VII	Preventive measures	Keeping workers safe, ventilation, lights, leak-spill control.	Engineering and storage precautions to be taken to avoid risk in recovery
VIII	First aid	Nature of first aid	To deal with accidents
IX	Preparation Data	Name of person and contact information	To contact for updating or for communicating new risks found (to environment, health or property).

5.2.3 The Material Safety Data Sheet (MSDS)

The chemical nature of the waste depends on the characteristics of the corresponding raw materials. The characteristics of raw materials are found in the MSDS which is, so to speak, a horoscope of every chemical. The information provided by an MSDS can be summarised in nine sections (table 5):

It will thus be found that MSDS is a very handy document for knowing the industry's own waste, making priority allocation for recovery, risk, taking precautions for storage and designing the reactors. MSDS data sheets are seldom complete, hence every industry must make efforts for collection of necessary information.

5.2.4 Case study

One industry found that its performance greatly improved after it based its raw material selection on the following four considerations:

- Elimination of feedstock impurities.
- Use of less hazardous raw materials.
- Reduction in the number of raw materials.
- Utilisation of waste materials from other processes.

The same industry later studied its water use with the same seriousness as raw material selection. The study showed that the water supplied was extremely hard and contained high TDS. The predominant calcium sulfate formed scales on process equipment that could be chemically removed. Instead, physical methods such as blasting and grinding were useful. The blow down rates from the cooling towers had to be very high to avoid formation of scales. Reverse osmosis technology was installed. The result contained only 5% impurity in raw water. The reject stream was acceptable for land irrigation. The RO technology was expensive, but proved to be cost effective at this refinery. The greatest benefit was reduction in hazardous wastewater sludge generated. In fact, saving in sludge disposal cost alone was found to be greater than the cost of pretreatment. (It is worth noting here that in the case of refineries, one kilo of solids in oily wastewater treatment can create as much as 10 kg of oily sludge, because the surfaces of the solids provide sites to which oil and wa-

ter can stabilise and adhere.) Consumption of chemicals for treating the boiler and cooling tower water reduced by more than 90%, and the resultant saving totaled about one third of the cost of the RO. Other savings resulted from reduced maintenance needs due to less scale build up in the water cooled heat exchanger.

Another industry was required to decide on a substitute for a currently used chemical. It had to see all aspects, else it would have solved one environmental problem and created another process problem (and that too would have got translated into an environmental problem). For example:

- High VOC liquid use substituted by low VOC, resulted in less air pollution, but in generation of more sludge.
- High VOC liquid use substituted by a water based use, resulted in less air pollution but created more water pollution.
- High VOC liquid use substituted by chlorinated solvents, resulted in less air pollution, but gave rise to more ozone depleting substances (ODS).

A third industry was required to use chlorinated solvents which created the following problems:

- At high altitude, they photo-dissociated, releasing chlorine which catalyses ozone destruction.
- They had global warming potential because of their ability to absorb infrared radiation due to the length of time that they remained in the atmosphere.
- Chlorinated solvents have a potential to form smog.

The industry had five chlorinated solvents to choose from. Ranking of these five candidates was done by giving grades in descending order A to E, with relatively environment friendly marked A and very unfriendly marked as E. The following table (6) emerged:

Table 6: Ranking of chlorinated solvents

#	Compound	Ozone depletion	Global warming	Smog formation	Negative marks
1	Methylene chloride CH_2CL_2	C	B	C	8
2	1 1 1 trichloroethane $CL_3C\text{-}CH_3$	D	D	B	10
3	Trichloroethylene $HCLC{=}CCL_2$	A	A	E	7
4	Tetrachloroethylene $CL_2C{=}CCL_2$	A	C	D	8
5	Chlorofluorocarbon [CFC-113]. $CL_2FC\text{-}CCLF_2$	E	E	A	11

Note – Solvents with high smog formation potential have low ozone depletion and global warming potential. This is because they are quickly oxidised by hydroxyl radicals present in the lower atmosphere and do not remain in the atmosphere long enough to be a concern in global warming or stratospheric ozone depletion.

5.3 Common Operations

We now review operations common to all industries such as cleaning, oiling, separation, house-keeping, etc.

Table 7: Commonly used organic solvents

#	Family	Common popular members
1	Aliphatic	Kerosene, naphtha
2	Alcohols	Butanol, ethanol, IPA, methanol
3	Aromatics	Benzene, toluene, xylene
4	Chlorinated HC	Carbon tetrachloride, chlorobenzene, methylene chloride, trichloroethylene
5	Esters, ethers	Ethyl acetate, ethylene glycol ethers
6	Fluorinated HC	CFC-11, CFC-113
7	Ketones	Acetone, methyl ethyl ketone MEK, methyl isobutyl ketone MIBK

(Chloroform, tetrachloroethylene are also common)

5.3.1 Cleaning

Cleaning is a simple act that is performed in almost all industries throughout the world, several times a day. These are small operations, but collectively they can affect maintenance and thereby contribute to overall costs. For the purpose of cleaning the vessels, mixers and equipment, solvents are used to dissolve and remove sol-

ids, scales or residues. Solvents are used for parts cleaning, vapour degreasing, semiconductor fabrication, paint stripping, etc. At present, the commonly used organic solvents are (see table 7).

The solvents once used for cleaning eventually reappear in some form or the other in the product or waste or the environment. According to one estimate, the profile of a solvent used and its fate is roughly as follows: where total solvent use is 735 + 68 = 803 (or 100%), recycled solvent reused is 68, atmospheric emission loss is 547.7, solid waste is 218.6 and effluent loss is 5.6 units. The total of all these figures is 839.9 (104.6%) which is more than the input of 100. This is not a mistake. When the solvent reappears, it brings along with it the dirt that is cleaned too. It is seen that 91.63% of solvent ends up as waste, hence, one needs to plan for WM.

Using a better solvent avoids adverse environmental impacts. Search for optional solvents is also necessary, so that the industry is not caught in a dilemma if some of the present solvents suddenly become unavailable.

Cleaning has to be scientifically done. Some workers are allergic to cleaning materials and good ventilation may be the answer. The spent cleaner should not be dumped anywhere. It can be used as waste fuel, or better still, recycled in the vacuum still. Precaution needs to be taken to prevent the spillage from reaching the yard drain and then the storm-water. This is especially true when there is a time-limit or emergency repair maintenance job. In order to stop the oil getting mixed in water, hanging baffles can be fitted in the storm drain which prevents emulsified oil from contaminating the surface water. The solvent mopping towels should not be thrown anywhere, but must go to proper washing and laundry disposal. Training should be given to workers on proper cleaning arrangements.

Cleaning can be improved if, to begin with, the need to clean is itself avoided or can be reduced by keeping general neatness. This can be done by modifying the present contaminants. Water conservation and wastewater minimisation can be achieved by resorting to high pressure spraying which reduces quantum of water. Some industries use abrasive help, for example, blasting by sodium carbonate, wheat starch or plastic balls.

Tank cleaning is another common operation. Waste reduction can be attempted here by using the particular equipment over and over again, without changing the production scheduling and thus without needing to clean it. When vessel washing is to be done, sufficient drain time needs to be allowed so that all the liquid is taken out. Some industries use countercurrent rinsing to reduce waste. If the equipment is cleaned immediately, the operation becomes easier; but if the material sticking to the equipment is allowed to dry, with the passage of time, the operation becomes complex. It is also preferable that all cleanings of the shop should not be mixed together. Keep them segregated.

A case study of a formulation industry reveals the following ways of cleaning (table 8):

Table 8: Cleaning in a formulation industry

#	Waste	Alternatives
1	Waste rinse water or absorbent	Reuse waste rinse water in future application Use high-pressure spray nozzle Use dry absorbents for cleanup Sweep floor to collect spilled product for use in formulation
2	Off-specification product	Control formulation process carefully Reformulate off-specification product instead of disposing Use minimal amount of rinse water Recondition and reuse drums Use refillable or returnable bulk tote bins.
3	Dust collected in air pollution equipment	Recycle dust into process from which it was generated.

Parts cleaning: This is necessary as metals are often coated with thin films of light hydrocarbon oils in order to prevent oxidation of the raw metal feedstock during shipping and storage. Heavy oils, esters and particulate matter tend to accumulate in these films during metal forming operations and these contaminants must be removed prior to surface treatment operations. Emissions are inversely proportional to the freeboard height. Thus if the free board height is doubled, emissions are halved. Lowering the condenser temperature also lowers the emissions. Other handy steps can be to (1) enclose solvent cleaning units; (2) improve parts draining before and after cleaning; (3) use entirely closed loop system, such as supercritical

CO_2 systems; and (4) use mechanical cleaning devices such as plastic bead blasting instead of solvents.

Equipment cleaning: Equipment that requires cleaning includes heat transformer surfaces, distillation column trays and pipes. The use of high pressure rinse system, mechanical wipers, 'pigs' (i.e. objects sent through pipes to scrape them clean) or compressed gas to clean lines, can reduce solvent usage in the cleaning of plant equipment. Blasting fouled surfaces with materials such as recyclable sand or dry ice is often a pollution prevention alternative to the use of solvents.

Storage tanks: They are used to dampen fluctuations in input and output flow. Storage tanks can be an important source of waste for three reasons, namely:

1. Tank bottom-residues comprise rusts, soil contaminants, heavy feedstock constituents and other heavy materials that are likely to settle from the process fluid being stored. If the material of the bottom contents are compatible with later process steps and will not generate more waste downstream, one can keep the contents in suspension by having mixers fitted. Also, agents that solubilise the bottom materials can be used, adding emulsifiers – but all with the same precaution, i.e., ensuring absence of non-compatibility and no waste generation downstream.

2. When liquid is standing in tanks, some evaporation takes place known as standing-breathing losses (apart from what happens during filling/withdrawing operations). Narrow tanks and insulated tanks whose contents undergo reduced temperature fluctuations have reduced breathing losses. Vapour recovery devices that trap and condense escaping vapours for return to tank can be used to reduce emissions from fixed roof stationary tank. When the tank is painted white, breathing losses are reduced by half. Breathing losses can be prevented by floating roof. Standing losses can be prevented when seams are welded rather than bolted or riveted. Emission loss, when gaskets are used, is four times less than without gaskets. Minimising the number of fittings and specials is also recommended.

3. Vapours that are displaced in loading and unloading operations can be a significant source of volatile hydrocarbon emissions

from storage containers. It is estimated by USEPA that as much as 1.5 kg of organic compounds can be lost per 1000 litres of gasoline transferred during uncontrolled goods train and tanker truck loading operations. Submerged loading is better than splash loading. Unloading operations also create waste when the storage material clings to the surfaces of the container being emptied. Tanks with a rusted interior have higher withdrawal losses because the rust provides surfaces to which the fluid being stored can easily cling. Also reduction of wall and column area per fluid volume change, decreases withdrawal losses. Spills should be managed by overflow control equipment and/or overflow alarms.

5.3.2 Good house-keeping practices

Good house-keeping practice starts at the entrance gate and ends at exit gate after covering all the areas, all the activities, all the time. A staff member dedicated to this task will work wonders, if he is simultaneously given freedom to offer suggestions to plug observed deficiencies. Some good housekeeping practices are:

- Tank covers should be in place (automated covers are preferred).
- Increase freeboard in the tanks, to avoid overflow without notice.
- Automation should always be working to minimise the workers' exposure and also reduce the drag out.
- A drying tunnel should be provided to ensure that dragged out vapours can be captured, rather than emitted.
- Distillation is recommended to clean and recover spent solvents.
- Vents should be marked and controlled to recover solvents escaping as hazardous air emissions.
- Demineralised and softened water should be appropriately used during operations like cooling tower make-up, boiler feed, etc.
- Increase tank agitation to its optimum speed.
- Examine whether 2-stage cleaning will create less waste than single-stage straight cleaning.

- Enclose the paint-gun cleaning section.

Good house-keeping should also achieve reduction of volume. Segregation is a simple, economic and handy technique to do this, in cases of spent oil, spent solvent, cyclone collected pesticides dust, cement dust, etc. However, in a pesticide unit, using separate bag houses at each process line will enable the industry to recycle collected dust into the respective product, uncontaminated. In a unit using resin as raw material, industry collected the waste resin and reused it in the next batch. A foreign-collaboration printed circuit board manufacturer used a filter press to de-water sludge to 60% solids and sold the sludge for metal recovery. Coolant oil is difficult to separate from water. If segregated, it can be subjected to ultrafiltration to remove recoverable oil from spent coolants. A paint industry used solvents for tank cleaning. The spent solvent was collected in segregated form and reused in paint formulations. In another industry, solvents were used to flush the spray-coating lines and the pumps. The solvents that reappeared were found suitable to serve as coating thinner after they were collected by segregation.

The segregation principle is thus useful for volume reduction and reuse of waste. A point, however, to be noted is that if concentration is suggested for recovery, then only can it be termed as waste reduction. Merely compacting/compressing to accommodate double the volume in a single drum is not real waste reduction but it can be considered an attempt at good house-keeping.

5.3.3 Solvents

Industry uses solvents for many purposes like degreasing, floor sealers, urethane-epoxies strippers, paint and furniture strippers, etc. Solvents are used in laboratories, hospitals, process reactors, etc. It is possible to have recovery plants with a capacity as small as 20 litres. Within a factory, the recovery plants can be either placed very near to the source of the spent solvent, or they may be placed centrally at one place. The central plant may either be dedicated to one solvent or may serve many solvents, one after another, after due cleaning. Segregated storage is the key to success. Solvents may be aliphatic/aromatic, halogenated or non-halogenated. Pretreatment is normally necessary before recovery. More than 50% of solvents are

recoverable but care must be taken to have less than 20% solids. The principle of better segregation applies here too. Processing begins in a solvent still – a distillation unit or a thin film evaporator. Some facilities have liquid-liquid extractor, two distillation columns in series, with a reflex splitter and reboiler, decanter and dryer, two-stage filtration, etc. If there is a cluster of industries in a large industrial estate, they will perhaps appreciate it if an authorised operating agency can fabricate a small mobile solvent recovery unit on wheels, which is brought to the individual industry site, recovers the solvent and returns the same then and there.

A number of solvents are available in the market. The frequently used ones are listed in table 9 below:

Table 9: Properties of solvents

#	Solvent	Boiling point		Flash point	
		Degree F	Degree C	Degree F	Degree C
1	Acetone	133	56.11	0	- 17.77
2	Benzene	176	80	12	-11.11
3	Cyclohexane	179	81.67	minus 4	-20
4	Ethyl alcohol	173	155.22	55	12.77
5	Methyl alcohol	147	63.89	52	11.11
6	Toluene	231	110.56	40	4.44
7	Aniline	363	183.89	158	70
8	Benzyl chloride	355	179.44	153	67.22
9	Ethylene glycol	387	197.22	232	111.11
10	Nitrobenzene	411	210.55	190	87.78

Higher flash point may be a better solvent, but one must also check for its TCLP test extract.

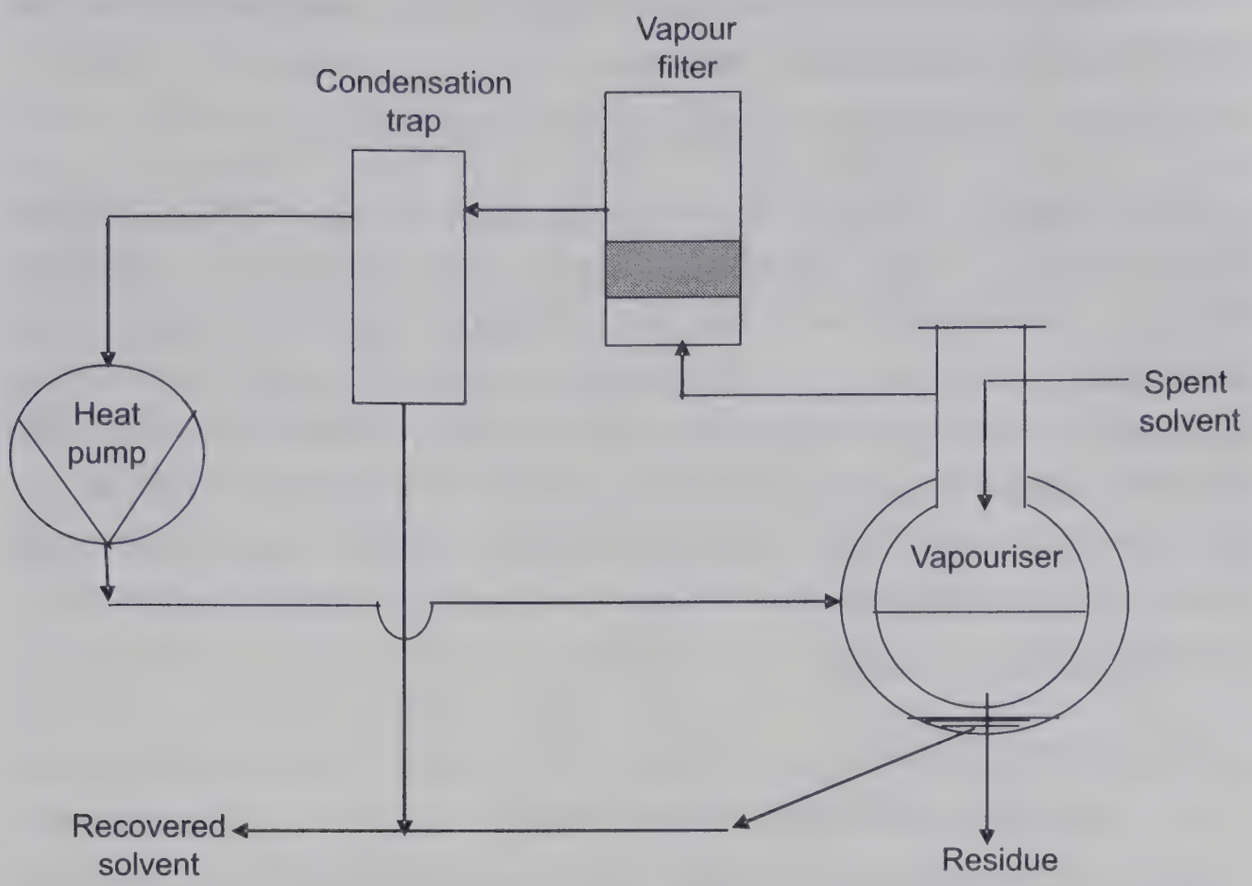


Fig 5.1 Vacuum vapouriser for on site solvent distillation

A few case studies are cited below:

- An industry was using two solvents, methyl isobutyl ketone and acitonitrile, in two successive steps in its production process. It reviewed the process and tried only acetonitrile at both places. The change worked.
- In another industry, toluene was replaced by isopropyl acetate, after considering the flash point. It worked and spent solvent was also found capable of being recovered/recycled.
- Pharmaceutical granulation and coating operation, if modified, eliminates use of chloroform, acetone, or methanol solvents.

Solvent cleaning and degreasing

Solvent cleaning and degreasing is the process of using an organic solvent to remove unwanted grease, oils, and other organic films from surfaces. The pollutants generated include:

(1) the liquid waste solvent and degreasing compounds containing unwanted film material; and

(2) the air emissions containing volatile solvents.

Procedure to prepare surfaces for painting is usually of three types, namely, cold cleaning, vapour degreasing and precision cleaning. Chlorinated solvents are adopted by industry because of their ability to dissolve a wide range of organic contaminants, low flammability and high vapour pressure (which allows it to evaporate at room temperature and leave a residue-free surface). But it has characteristics of toxicity and ODS, and therefore, there is presently a search for an alternative.

The trials are with:

- citrus products;
- hot water alkaline cleaners; and
- high pressure hot water washers without solvents or detergents.

Recycling waste solvents:

1. Cascade reuse: High quality solvent used once for precision cleaning can be reused without treatment for a less demanding function.

2. Distillation: (Heating a solvent until it vapourises and then condensing the vapour.) To minimise thermal decomposition of solvent at high temperature, distillation is done in vacuum. Or, steam is injected into the solvent at high boiling point, so that an azeotropic mixture is formed and boiling point is low. The water is then separated. Some industries prefer this procedure over centrifugation, filtration, ultrafiltration, reverse osmosis and activated carbon adsorption.

5.3.4 Other recoveries

(A) *Oil recovery*

Waste oil includes transformer oil, equipment oil, motor oil, cutting oil, soluble oil, diesel oil, gasoline additive, brake fluid, hydraulic oils, etc. First step for considering recovery is sampling — to determine the percentage of recoverable oil, bottom sludge and wa-

ter. Laboratory test will indicate flash point, PCB content and metal content. The spent oil awaiting recovery is first received into tanks. Phase separation then begins. Oily phase is transferred to a series of treatment tanks, where temperature is adjusted and chemicals added to separate suspended water while filters separate suspended solids. Filtrates are disposed of by de-watering through vacuum filter or press, or they are land-filled.

(B) *Waste exchange*

Waste exchange is an environmentally acceptable way of 'getting rid' of waste. There should be a place for 'data exchange' and a place for actual 'material exchange'. Salvaged materials such as acids, alkalis, spent catalysts, metal processing debris, petroleum derivatives, solvents, wood scrap, saw dust, bagasse, filter mud, etc., can be disposed of if authorised operating agencies and private companies accept to be data exchange or material exchange points.

However, there are certain difficulties. The purity of procured material is uncertain and varies every time. The supply-demand link is unreliable and may not always match. Long distance transport may sometimes be involved. An extension of this idea is to locate such industries together so that they may mutually use each other's waste as raw material. (This concept is discussed in Chapter 6.)

(C) *Treatment*

Treatment is another common feature in all industries. It means either changing the hazardous characteristics or reducing the volume or altering the complexity of waste before disposal. It can also mean recovery, where reuse itself is a way of disposal. Most common types of treatment are:

- Physical (solid-liquid separation, membrane separation, evaporation, distillation, stripping, solvent extraction, adsorption, etc).
- Chemical (neutralisation, precipitation, ion exchange, oxidation/reduction, solidification, fixation, dechlorination, etc).
- Biological (activated sludge, trickling filter, bio-digester, bio-composting, etc).

- Thermal (rotary kiln, fluidised bed, multiple hearth, liquid injection, etc).

(D) *Land disposal*

Though this common operation is lowest in the hierarchy, it is the most important. Land disposal is done in open dumps, surface impoundments, sanitary landfills, secured/engineered landfills, underground injection wells, etc. The disposal should be in conformity with the conditions laid down in the individual authorisation and consent letters issued by the SPCB.

5.3.5 Case study (SSI)

Recovery should not only be the concern of large scale industries alone. There are instances when even SSI units in industrially backward areas have undertaken the job of collecting waste from others, refining it and returning it to the same party, with more purity than the virgin material. For example, the (O-O) process of manufacture of n-butyl, iso-butyl, amyl, iso-octyle, decyl and tridecyl alcohols leaves behind a residual substance, a typical analysis of which is as follows (table 10):

Table 10: Analysis of residual substances of O-O process

#	Ingredient	%	#	Ingredient	%
1	N-Butyraldehyde	9.26	4	N-Butanol	5.83
2	Ethyl propyl alcohol	1.03	5	Lights	1.7
3	2-Ethyl hexanol	18.79	6	C6-C18 fractions	62.19
(The rest is moisture)					

The specific gravity of the substance is between 0.84 and 0.88, and the colour is yellow-amber. This is essentially a mixture of thinner and solvents of lower range of boiling point. In this unit, the thinner/solvents of lower range of boiling point (like serial numbers 1, 2 and 3 of the table above) act as a distillate leaving behind thinner/solvents of higher range of boiling points. Both the separated portions could be applied as reclaimed thinner for specific purposes. Neither of them needed pretreatment nor left any residue for disposal.

5.3.6 Chloro-fluorocarbons (CFCs)

Planet earth, at a higher level, has a layer of ozone that protects it from harmful levels of ultraviolet radiation. The increased radiation could cause a higher incidence of skin cancer and create mal-effects on the earth's life-supporting eco-system. Chemicals called chloro-fluorocarbons cause depletion of the ozone layer. CFCs are used in the electronic industry, in cleaning, degreasing, refrigeration, blowing and as intermediates. Minimising CFCs can be achieved by using standard tools like substitution, recycling and good operating practices. CFCs can be substituted by other chemicals, but none of them are non-toxic. TCA (1,1,1-trichloroethane) is preferred among them, as it is not a confirmed carcinogen and it has only 10% ozone depletion potential as that of CFC-11 and it is not smog-generating. As process substitution, aqueous cleaning is suggested. Recycling of CFC vapours through carbon adsorption or recycling of waste on-site is being attempted. Increasing the freeboard at degreaser, fitting a refrigerated chiller, employing condenser coils are ways of modifying equipment. As good operating practice, measures include waiting till solvent dripping ceases, covering equipment while not in use, etc. We shall have to start practising some of these right now, because at some time in the near future, CFCs may be out of the market altogether.

5.4 Managing Utilities

We now examine how waste and loss can be minimised in utilities.

5.4.1 Boiler efficiency tips

(A) *Boiler performance*

Boiler efficiency can be improved through proper maintenance and monitoring of operation. The seven tips presented here are guidelines for improving boiler efficiency.

1. Conduct a flue gas analysis on the boiler every two months to test for fuel/air ratio setting and adjust air/fuel ratio to optimise efficiency. Optimal percentages of O_2, CO_2 and excess air in the exhaust gases are shown in table 11:

Table 11: Optimal percentages and excess air in exhaust gases

#	Fuel	O_2 (%)	CO_2 (%)	Excess air (%)
1	Natural gas	2.2	10.5	10
2	Liquid petroleum fuel	4.0	12.5	20
3	Coal	4.5	14.5	25
4	Wood	5.0	15.5	30

The air fuel ratio can be periodically adjusted to the recommended optimum values; however, a boiler with a wide operating range may require a control system to constantly adjust the air-fuel ratio.

2. A high flue gas temperature often reflects the existence of deposits and fouling on the fire and/or water side(s) of the boiler. The resulting loss in boiler efficiency can be estimated on the basis that 1% efficiency loss occurs with every 40 ^{0}F (19 ^{0}C) increase in stack temperature.

Hence, stack gas temperature should be recorded immediately after boiler servicing (including tube cleaning) and this value should be used as the optimum reading. Stack gas temperature readings should be taken on a regular basis and compared with the established optimum reading at the same firing rate. A major variation in the stack gas temperature indicates a drop in efficiency and the need for either air-fuel ratio adjustment or boiler tube cleaning. Ask the supplier how the stack temperature rises with maladjusted air-fuel ratios. In the absence of any reference temperature, it is expected that stack temperature will be less than 100 ^{0}F above the saturated steam temperature at a high firing rate in a saturated steam boiler. (This does not apply to boilers with economisers and air pre-heaters.)

3. After an overhaul of the boiler, examine the tubes for cleanliness after thirty days of operation. The accumulated amount of soot will indicate the frequency of boiler tube cleaning.

4. Check the burner head and orifice once a week and clean if necessary.

5. Check all controls frequently and keep them clean and dry.

6. For water tube boilers burning coal or oil, blow the soot out once a day. It is estimated that operating the boilers without cleaning

for a week can result in an efficiency reduction of as much as 8%, caused solely by soot accumulation.

7. Purity of water used for steam generation is extremely important. Impure water cannot be used as boiler feed. Water treatment prevents the formation of scales and sludge deposits on the internal surfaces of boilers. Scale formation severely retards the heat flow and causes overheating of metal parts.

(B) *Combustion in oil-fired boiler*

A boiler operating with too much excess air can result in unnecessary fuel consumption. Best performance can be obtained by the installation of an automatic oxygen trim system that will automatically adjust the combustion to changing conditions. Alternatively, the portable flue gas analyser can be used in a rigorous program of weekly boiler inspection and adjustment for boilers. The optimum amount of O_2 in the flue gas of an oil-fired boiler is 3.7%, which corresponds to 20% excess air.

5.4.2 Energy

Energy is required in an industry for various operations. In the chemical industry, it is needed to drive endothermic reactions, to carry out mass transfer operations, to provide optimum reaction conditions of temperature and pressure, to drive separation process, to power control and communication systems and to provide a satisfactory work environment. Energy requirements are of different types: mechanical energy is used to compress gases for high pressure reactions; thermal energy is used to raise temperature of a reaction; and electrical energy is needed for electrolytic processes, for driving pumps or to illuminate works. Energy is derived from fuels. Fuel preference depends on its calorific value, ease of handling and distribution, reliability, by-products (ash, sulphur), and maintenance. Normal fuel preference, in descending order, is electricity, gas, hydrocarbon liquid, fuel oil and coal. The following aspects may be noted:

1. Energy is needed to run the batch reactors in an industry. Batch reactors are fill-and-draw type of vessels, with about 1 to 20 cu.m capacity, the material of construction being metal lined with glass, ceramic, rubber- or resin-lined and equipped with a stirrer,

coiled pipes, jacket, etc. A cooling coil helps exothermic reactions or crystallisation. A continuous reactor can balance exothermic and endothermic reaction needs, and it also economises on reactants. It is therefore preferred.

2. Cooling water should not pass once through. Latent heat required to evaporate 1-2% of water lowers the temperature of remainder water.

3. Steam is useful as a heat transfer medium. It has a high heat content, it can be easily distributed, its flow is easily controllable, it is non-combustible and will not support combustion, it is non-toxic, and relatively non-corrosive. Steam can be used as a source of power as well as heat. If high pressure steam from a boiler is passed through a turbine or alternator set to generate electricity, then exhausted low pressure can be supplied as process heat. Thus, most of the energy in the original fuel is fruitfully used rather than rejected into the atmosphere. (This is done in sugar factory turbines instead of throttling.)

4. Some chemical reactions are exothermic. The heat generated can be collected and used to heat water or converted to steam for using in process or for heating the raw material (as in a paper mill). This simultaneously controls the temperature and uses it. Partial oxidation reactions of hydrocarbons are highly exothermic, but reaction temperatures are normally lowered to prevent by-product formation.

5. Separation process is energy intensive and hence should be reviewed in order to select the optimal method. Distillation should be considered as its optimisation depending on a combination of reflux ratio, number of plates and diameter of column.

6. To save energy while drying, pre-concentration of slurry by mechanical means like filter press or centrifuge is recommended. Degree of diluents' removal is determined by particle size of solid and feed characteristics for the selected dryer, e.g., pumpable slurry, performable paste, hard lumps, etc.

7. Restriction of losses is an important consideration in energy input.

- Lagging: Hot pipes usually lag due to magnesia (MgO) or calcium silicate ($CaSiO_3$) or with mineral or mineral wool, whereas expanded polystyrene is utilised for cold pipe-work.
- Leaks: Furnaces should be operated at slightly negative pressure, which avoids outward loss of hot gases. Leaks from flanges and valve packings on steam distribution systems should be repaired. Steam leaks can cause appreciable loss of energy. For instance, a 3 mm dia. hole in a 20 atmosphere steam pipe will cause a loss of 10 tonnes of high quality steam per week.

8. Energy use is also dependent on the bends and fittings. Bends are better than elbows or sharp curves for co-efficiency of flow. While a 45^0 elbow shows 0.3, a 90^0 bend shows 0.8. Coupling is always preferable. As co-efficiency at entry to pipe from large vessel is 0.5, open expanded bend is preferred.

9. As a case study, a shell and tube heat exchanger cools 98% H_2SO_4 (100 kg/sec, say) from 60 to 32 ^{0}C. The cooling water is 10 ^{0}C and 50 kg/sec. Industry decided to opt for and run a counter-current. It was found that it needed 70% less cooling area than when it was co-current earlier.

5.4.3 Pumps

Pumps are widely used for the transfer of liquids from one place to another, and from one level to another. Pumps are usually driven by electric motors but can also be driven by compressed air or hydraulics. There are many types of pumps in use in industry, among which are:

- centrifugal pumps, used for transfer of large volumes;
- metering pumps, used for precise delivery of liquids to a point of application and ensuring constant discharge, regardless of back-pressures in the lines; and
- progressive cavity pumps or peristaltic pumps, used for delivery of very viscous materials.

Measures to improve pump efficiency:

- Shut down unnecessary pumps.

- Restore internal clearances if performance changes significantly.
- Trim or change impellers if head is larger than necessary.
- Control by throttle instead of running wide open or bypassing the flow.
- Replace oversized pumps.
- Use multiple pumps instead of one large pump.
- Use small booster pumps.

5.4.4 Fans

Fans provide the necessary energy input to pump air from one location to another while they overcome the resistance created by equipment and the duct distribution system. Factors that can reduce fan efficiency are: excessive static-pressure losses through poor duct configuration or plugging, duct leakage, improperly installed inlet cone causing excessive air recirculation, oversized fan and buildup of negative pressure. Reductions in exhaust airflows are usually obtained by adjustments of dampers in the duct. More efficient methods of volume control are: install inlet damper control, reduce the speed of the fan and provide variable speed control for the fan.

5.4.5 Air compressors

Air compressors often consume large amounts of electricity. There are two types of air compressors: reciprocating and screw compressors. Reciprocating compressors operate in a manner similar to that of an automobile engine – using a piston to compress the air. Screw compressors work by entraining the air between two rotating augers. The space between the augers becomes smaller as the air moves towards the outlet, thereby compressing the air. Screw type compressors, especially older models, use more energy than reciprocating compressors. This is especially true if the compressor is oversized because the screw compressor continues to rotate, whereas a reciprocating compressor requires no power during the unloaded state. Energy used by air compressors can be reduced by:

- Repairing air leaks.
- Reducing operating pressure.

- Recovering heat from compressor exhaust or cooling water.
- Using outside air.
- Installing low pressure blowers where applicable.

5.4.6 Some case studies

(A) ***An industry's heat exchanger generated waste.***

The following minimisation methods helped:

- It was found that the heat-exchange surfaces had become rough over the years. This was replaced partly by electro-plated or Teflon tubes, depending on the importance of positions.
- For cleaning, hydro-blasting was done in place of chemical cleaning wherever possible.
- Controlled bypassing or pumped recycling was done to maintain turbulence during turndown.

(B) ***An industry had a number of tanks which it cleaned using solvents or inorganic based cleaning solutions. This generated cleaning waste.***

The following minimisation methods helped:

- The unit maximised dedication of process equipment, i.e., the same equipment was used for the same process, over and over again.
- It used mechanical means and shoes to recover cling of product prior to rinsing.
- It used closed storage and transfer system.
- It provided sufficient drain time for liquid.
- It used high-pressure spray nozzles.
- It used countercurrent rinsing.
- It cleaned the equipment immediately after use.

(C) ***Maintenance of vehicles creates a variety of wastes, like 'parts cleaning' waste, waste oils and coolants, spent lead-acid batteries and paint waste (table 12)***

Table 12: Wastes from cleaning of vehicles

Waste category	Alternatives
A. Parts cleaning waste	Operate solvent sinks properly Avoid contamination of solvents Install lids on solvent tanks Increase freeboard space on tanks Use commercial solvent recycling service Employ on-site recycling of solvent using distillation and/or filtration Substitute biodegradable cleaners for solvents Remove sludge frequently from cleaning tanks Use multiple rinse tanks Recycle rinse solutions
B. Waste oils and coolants	Change fluids only at required intervals Store oil separately from other hazardous waste Recycle used oil through a registered recycler Burn used oil in on-site heating units, if permitted Extend oil change intervals with fluid filtration systems Avoid spillage Use drip pans to catch leaking fluids
C. Spent lead-acid batteries	Return to manufacturer or recycler for reconditioning
D. Paint waste	Reduce use of solvent and metal based paints, wherever possible Use water based coatings Use high solids coatings such as powder coating Implement better operating practices for painting Segregate all waste streams Use equipment with high efficiency and low overspray Reduce spent filter generation by covering filters with cheesecloth Apply spent solvent WM techniques to dirty thinners Use gun washer for equipment cleaning Train spray operators on proper application technique Use materials in concentration below ignitability level Allow saturated rags to dry before disposing Use water based material and non-hazardous solvents Segregate incompatible wastes to avoid combustion or reaction.

(D) ***Construction activity goes on in all the industries either as additions, alterations or as expansion for colony or administrative buildings. Construction activity generates wastes. Suggested efforts for WM are (table 13):***

Waste category
A = Spent solvents and cleaners
B = Acid/alkaline cleaners
C = Ignitable wastes

(It will also generate paint waste and vehicle maintenance waste, which is akin to what is stated in the table above.)

Table 13: Wastes from construction industry and options

Waste category	Alternatives
A. Spent solvents and cleaners	Avoid cross contamination of solvents Avoid water contamination of solvents Remove sludge continuously Keep solvent containers covered to reduce evaporation Monitor solvent composition Consolidate cold cleaning operations Use mechanical blasting for paint stripping Use non-hazardous or non-chlorinated solvents where possible Use solvent recycling service Consider using on-site solvent distillation recovery unit
B. Acid/alkaline cleaners	Improve operating practices Avoid spillage and dripping of acid/alkali cleaning solutions Segregate acid and alkaline wastes Substitute non-hazardous or less-hazardous materials Remove sludge from acid or alkaline bath frequently Use mechanical cleaning method where feasible Avoid cross contamination Reuse by filtering and rejuvenating
C. Ignitable wastes	Use materials in concentration below ignitability level Allow saturated rags to dry before disposing Use water based material and non-hazardous solvents Segregate incompatible wastes to avoid combustion or reaction.

5.4.7 Cooling water

Cooling water is needed in all industries. Pretreatment of the feed gives many advantages.

Qo is the water quantity coming in and has Co as concentration of hardness.

Qe is the water quantity evaporated in the process.

Qb is the water quantity of blowdown and has Cb as concentration of hardness.

Qw is the windage loss with Cb as concentration of hardness.

Given the

(1) Flow rate in MGD Qe = 1.4, Qw = 0.041 and Qb = 0.54.

(2) Hardness in ppm as $CaCO_3$ is Co = 750 and Cb = 2600.

(3) Pretreated feedwater hardness is 38 ppm.

(4) Water in cooling tower is 34 times as hard or 1292 ppm

Mass balance for hardness can be stated as: $QoCo = QbCb + QwCb$

Mass balance for water can be stated as: $Qo = Qe + Qb + Qw$

After pretreatment $Co = 38$ ppm

$$Cb = 34 \times 38 = 1292 \text{ say } 1300 \text{ ppm}$$

Qw and Qe (windage and evaporation) are the same whether pretreatment is given or not. Now, solving for Qo

$QoCo = QbCb + QwCb$

$Qo \times 38 = Qb \times 1300 + Qw \times 1300$

$Qo/34 = Qb + Qw$

$Qb = Qo/34 - Qw$

$Qo = Qe + Qb + Qw$

$Qo = 1.4 + Qb + 0.041$. (But $Qb = Qo/34 - Qw0.041$. We substitute to get)

$Qo = 1.4 + (Qo/34 - Qw0.041) + Qw$

$Qo = 1.4 + Qo/34$

$33Qo = 47.6$

$Qo = 1.4424$.

Therefore Qb = zero, and there is virtually no blowdown required from the cooling tower.

If previously (when no water pretreatment was given) wastewater was physically 0.9 mgd, now 60% waste water volume is reduced.

This shows the need for pretreatment, to minimise water use.

5.5 Hardware and Machinery

5.5.1 Agitation and mixing

Waste increases when efficiency of process decreases. Efficiency of process decreases the effective agitation and mixing of solids,

liquids, gases, catalysts and temperature during the process. The following aspects may be noted:

1. Agitation can be used for:

- Suspending solid particles.
- Blending miscible liquids, for example, methyl alcohol and water.
- Dispersing a gas through the liquid in the form of small bubbles.
- Dispersing a second liquid, immiscible with the first, to form an emulsion or suspension of fine drops.
- Promoting heat transfer between the liquid and a coil/jacket.
- Suspending solid particles of catalyst.

2. The tank bottom should be rounded and not flat. This will eliminate sharp corners or regions into which fluid currents would not penetrate. The liquid depth should be approximately equal to the diameter of the tank. The impeller causes the liquid to circulate in the vessel and eventually return towards the impeller where there is need for baffles to reduce tangential motion. This is a simple alteration, but will help a lot.

3. While there are two classes of agitators, namely, axial-flow impellers and radial-flow impellers, the impellers themselves are of three types catering for the liquids of low to moderate viscosities. These are propellers, turbines and high-efficiency impellers, each having many subtypes: for example, three blade marine propellers, straight blade turbines, disk turbines, concave-blade impellers and pitched-blade turbines. For very viscous liquid, helical impellers or anchor agitators are recommended.

4. The flow pattern in a reactor is basic for contact opportunity and conversion. This in turn depends on the type of impeller, characteristics of the liquid (especially the viscosity), size and proportion of tank, baffles and the impeller itself. The liquid velocity so caused has three components, namely, radial, longitudinal and tangential or rotational. The first two are good for mixing but the third creates a vortex. Such swirling perpetuates stratification, throwing solid particles outside by centrifugal force, and from there sliding downwards

by the wall to the bottom centre of the tank. As the solid particles accumulate, instead of mixing, its reverse, i.e., concentration occurs. The swirling is enhanced if the speed of the impeller is high and at its extreme may even reach the bottom.

5. This necessitates prevention of swirling. If the tank is small, mounting the impeller off-centre can be a quick solution. In a large tank, the purpose is served by installing baffles which impede rotational flow without interfering with radial-longitudinal flows. Baffles are simple vertical strips at right angles to the wall and two to four numbers will prove adequate. The width of the baffle should be one twelfth to one eighteenth of the tank diameter.

6. Vertical cylindrical is a popular geometry for process tanks. For better service, see that the depth of liquid is equal to or greater than the diameter of the tank. If the depth of the tank is greater, mixing may become ineffective. Then, two or more impellers should be mounted on the same shaft. Keep the lowest impeller as straight-blade radial flow unit and the upper one as axial flow impeller. Arrange the bottom impeller one diameter above the bottom of the tank. If the diameter is substantially big, a draft tube will have to be provided at the center.

7. If dispersion of gas in the liquid is required, then passing it through a sparger with multiple orifices, porous ceramic or open pipe, is recommended.

8. When solids are merely suspended in a liquid, the size and surface area of particles exposed to the liquid are fixed, as is the total volume of the solids. At higher shearing rates, however, agglomerates may be broken up, and if the material is fragile or sensitive, it may be degraded, diameter reduced or new surface created. This is especially important in fermentation (or biological oxidation tanks) and similar operations in which biological cells may be destroyed if local shear rates in the vessel are too high.

9. Liquid-liquid dispersions – Various types of equipment can be used to disperse one liquid, for instance, benzene, in an immiscible liquid such as water. A stirred tank or an in-line mixer can produce drops in the size range of 0.05 to 1.0 mm.

10. The closer one can adjust the mixer to the above recommendations, the better will be the results, as the mixer will give maximum advantage of materials and also consume less power.

5.5.2 Drying of solids

Drying is a common operation in many industries. The following points may be noted:

1. Drying is meant to get the material into solid form. The solids can be of different constituencies such as flakes, granules, crystals, powder, slabs or continuous sheets, depending on what is the degree of drying required to be done.

2. There are various types of dryers such as:

- Dryers in which solids are directly exposed to a hot gas (usually air).
- Dryers in which heat is transferred to solid from an external medium such as condensing steam (usually through a metal surface with which the solid is in contact).
- Dryers that are heated by di-electric, radiant or microwave energy.

3. A large variety of drying equipment is available such as tray dryers, screen-conveyer dryers, screw-conveyer dryers, tower dryers, rotary dryers, turbo-dryers, fluid-bed dryers, flash dryers, spray dryers, thin-film dryers, drum dryers, etc., or a combination of these. These are not competitors but complementary items.

4. Study of patterns of gas-solid interaction in dryers is required to be carried out. These are either gas flow across the static bed of solids, or gas passing through a bed of preformed solids, showering action in a rotary dryer, fluidised solid beds, or concurrent gas-solid flow in a pneumatic-conveyer flash dryer.

5. Examine if it is necessary to pre-treat the liquid feed prior to drying to remove impurities that cannot be permitted to appear in the dried product. It is essential that the engineer pay attention to the whole isolation process and not focus narrowly on the drying step alone.

5.5.3 Operations involving particulate solids

In an industry, many raw materials, intermediates, by-products, products or waste products are in solid form. Solids are more difficult to handle than liquid or gas. The nature of the material may be hard, abrasive, tough, rubbery, soft, fragile, dusty, cohesive, free-flowing or sticky.

1. Coarse solids (like coal, gravel, etc.,) are usually stored outside in large piles. This can lead to environmental problems as dust gets air-borne or its soluble part can leach into the soil.

2. Valuable or too soluble solids cannot be so stored in the open. They are housed in bins, hoppers or silos. Solid material from bins should not be removed from the sides, but from a bottom opening to avoid tunnel-flow or rat-holes in the stock left behind. If the material is sticky, solid or fine dry powder, the use of vibrators or internal plows or jets of air come in handy to get the flow started and to keep it going.

3. Transporting the solid material is conveniently done by pneumatic conveyers, belt conveyers, bucket elevators or closed-belt conveyers with a return leg. If the distance is substantial, as in case of bringing sand or limestone to a cement plant, patrolling may be necessary to ensure that there are no fugitives.

4. The manufacturing process may include mixing of solids. When the solid is free flowing or cohesive, the mixing will resemble liquid blending. For cohesive solids use of change-can mixers, double-motion paste mixers (pony mixer or beater mixer), kneaders-dispersers-masticators, mixer extruders, or pug-mills are recommended.

5. When the material is non-cohesive, mixing is to be done by slow speed agitation with impeller or by tumbling or by centrifugal smearing and impact. Like ribbon blenders, one can have internal screw mixers.

5.5.4 Mechanical separation

'Separation' is an extremely important operation in the manufacture of chemicals. One type is based on diffusional operation intra-phase (like gas absorption, humidification, distillation, leach-

ing-extraction, drying of solids, membrane separation and crystallisation) while another is straightforward mechanical separation (especially seen at a large number of small scale industries). The following points may be noted:

1. Mechanical separation is applicable to heterogeneous mixtures of materials and not to homogenous solutions.

2. Mechanical separation technique employed depends on the size, shape, density, moisture content and electrical-magnetic properties of the component ingredients of the mixture. This is required to be ascertained in advance.

3. A pilot study should help the industry to decide the type of screen required, for example, like stationary screen, gyrating screen, vibrating screen, etc.

4. Filtration is a gadget for removal of solid particles from fluid through filtering medium – septum, on which solids are deposited. Many varieties are available such as filter press, shell-and-leaf filters, automatic belt filters, discontinuous vacuum filters, continuous vacuum filters, rotary-drum filters, rotary-drum pressure filters, precoat filters, horizontal belt filters and centrifugal filters. Tailor-made combinations are also possible.

5. Washing the filter cakes is an attendant duty. To wash soluble material that may be retained by the filter cake after filtration, a solvent miscible with the filtrate is used as a wash. Water, being a universal solvent, is the most common wash liquid. The rate of flow of wash liquid and the volume of the liquid must be observed to reduce the solute content of the cake to the desired degree.

6. Washing generates effluent which consists essentially of the filtrate that was left on the filter and which is swept out by the first wash liquid without appreciable dilution. Where the particle size of the cake is small, as much as 90 per cent of the solute in the cake can be recovered during this stage. In the third stage, the concentration of solute in the effluent is low and the remaining solute slowly leaches from the cake. It is important to examine whether the third wash can be used as first wash for the next cycle.

7. Filtration can also be done using membranes. There are many varieties. Micro-filtration is used for particle size of 0.5 to 5 μm,

ultra-filtration covers a large range of 0.5 μm to 0.001 μm and hyper-filtration is used for separation of small molecules or ions. Reverse osmosis occurs by a solution diffusion mechanism in the dense polymer rather than by a screening action on the membrane surface.

5.5.5 Equipment modification

Equipment modifications should always be periodically considered as one may find that the downtime, chemical input, water cost, etc., are reduced and thereby waste gets minimised.

Based on discussions with experienced chemists and engineers, here are a few tips on production technique modifications to minimise waste:

1. Chemical reactions:

- Optimise the reaction variables and improve process controls (like temperature, pressure or time).
- Optimise the reactant addition method.
- Eliminate the use of toxic catalysts, by choosing alternatives.
- Improve the reactor design (as indicated in the above section).
- Use instrumentation (new or re-calibration) and preferably micro-processor.
- Distribute material efficiently, using MIMO technique (multiple inlets multiple outlets).

2. Filtration and washing:

- Eliminate or reduce the use of filter aids and disposable filters.
- Drain the filter before opening to save material lost in waste.
- Use countercurrent washing, and preferably preserve the last dilute for next batch as first wash.
- Recycle the spent wastewater suitably.
- Maximise the sludge dewatering, making it easier for transportation and/or recovery.

3. Parts cleaning:

- Enclose all solvent cleaning units to prevent loss and fugitives.
- Use refrigerated freeboard on vapour degreaser unit, for same purpose as above.
- Improve the lifting operation of job-parts draining, before and after cleaning.
- Use mechanical cleaning devices rather than hosing out.
- Use plastic-bead blasting to reduce washing water.

4. Surface finishing:

- Remove contaminants.
- Redesign the space and placing of job-part racks, to reduce the drag-out.
- Reuse the rinse water and control the quantity by flow control valves.
- Install spray or fog nozzle rinse system for reducing the quantity.
- Install drag-out recovery tanks to save materials.
- In order to save materials, join the drain, install drip racks and drain-boards.

5. Surface coating:

- Use airless air-assisted spray guns and electrostatic spray-coating system.
- Use heat units to control coating viscosity.

6. Equipment cleaning:

- If many pieces of equipment are required to be washed every shift, high-pressure rinse system should be pressed into service to replace the normal tap.
- Use mechanical wipers.
- Use countercurrent rinse sequence at the tanks.
- Reuse spent rinse water.
- Use compressed gas to blow out choked lines.

7. Spills and leaks:

- Use bellow-sealed valves.
- Install spill-basins or dykes.
- Use mechanical seal pumps or seal-less pumps.
- Maximise use of welded pipe joints, avoid leakages through joints or collars and use longer pipes to avoid use of joints.
- Install splash guards, drip boards and clink valves.
- In a sugar factory, oil trays were placed at the ball bearing stand holding milling wheels extracting juice from cane. The trays being visible could be emptied out periodically. In a Formica industry, phenol trays were not visible being at low level, near the wall, away from operator-supervisor and in the dark. A mirror placed for reflection, provided visibility.

5.6 Process Modification

Reactors: Reactors are key elements where most of the undesired by-products that will eventually make up the waste streams are created. The ideal situation is when:

1. The reactor produces maximum amount of product and minimum of by-product;

2. The reaction chemistry can be reviewed and potentially changed;

3. Storage of hazardous waste can be avoided;

4. Changes in catalyst formulation are possible, which may reduce attrition and deactivation, resulting in less catalyst waste;

5. New reaction configurations can be designed to reduce waste by combining reaction plus separation operation in one unit.

Maximising selectivity: The tools are:

- To improve physical mixing in the reactor.
- To distribute feeds so as to avoid short-circuiting. This will ensure that as much of the feed as possible is in the reactor for the optimum residence time.
- To premix reactants so as to obtain better contact opportunity.

- To provide a separate reactor for recycle streams if there is no reversible reaction when by-product is formed.
- To examine heating and cooling techniques, particularly focusing on avoiding cool spots and hot spots.
- To eliminate use of direct steam contact.

Changing process chemistry: In some cases, there are such undesirable side reactions that substantial avoidable waste is created. Such a situation makes the step of change in raw materials very attractive. As an example, when acrolynitrile is produced via the ammoxidation of propylene, side reactions create waste acrolein, acetonitrile and hydrocyanic acid. Producing acrolynitrile through the cyanation/oxidation of ethylene might significantly reduce the wastes associated with acrolynitrile production. New catalyst technologies have considerable potential for reducing waste. For example, toxic chloroorganic by-products in the production of acetaldehyde can be reduced by more than a factor of 100 through the use of a retrofit catalyst system.

Prolonging catalyst life: Catalysts lose their effectiveness during use but can be reused after undergoing a regeneration process. Careful control of the regeneration process can maximise the quality of the regenerated catalyst while minimising the damage caused to the catalyst during regeneration. Catalysts can sometimes be modified so that they can last longer between changeouts, resulting in fewer waste-generation shutdowns for catalyst changeouts.

Combined reactor/separators: If so combined in a single unit, it can offer many advantages. There are many such examples.

- One standard example is the catalytic distillation used in the production of methyl tert-butyle ether (MTBE) where it relies on large difference in volatility between the reactants and products.
- Membrane technology offers other new technologies for combining reaction and separation activities when the product molecules are smaller than the reactant molecules. This holds particular promise for reversible reactions because the product is removed as it is formed and can be quickly placed under conditions in which the reverse reaction is unlikely

to occur. Removal of product also makes the reactor advantageous if the product can react with a reactant to form a waste.

Heat exchangers: They can be a direct source of waste when high temperature causes the fluids they contain to form sludges which reduce efficiency. One way to reduce sludge formation is to reduce the temperatures used in heat exchangers. Excessively high temperatures are frequently used because of the availability of process steam at fixed pressures but these can be modified. Sludge build-up can also be minimised through the use of online cleaning techniques, scraped wall exchangers and non-corroding tubes. Anti-foulants also prevent sludge build-up. An alternative to the shell and tube heat exchanger is the plate and frame separation equipment which minimises routine waste, controls excursions in operating conditions and thus improves efficiency.

Distillation: Distillation columns produce waste due to inefficiency in separating materials. Efficiency can be improved as follows:

1. Increase the flux ratio, add a section to the column, retray/repack the column or improve feed distribution so as to increase column efficiency.

2. Insulate or preheat the column feed to reduce the load on the reboiler. A higher boiler load results in higher temperature and more sludge generation.

3. Reduce the pressure drop in the column which lowers the load on the reboiler.

4. Vacuum distillation reduces reboiler requirement, which reduces sludge formation.

Changes in tray configurations or tower packing may prevent pollution from distillation processes. At one facility, the conventional packing in a distillation column was replaced with high-efficiency structured packing conversion resulting in more product available for sale and a halving of still bottoms sent for incineration.

5.7 Catalysts

A discussion on WM will be incomplete without understanding the role played by catalysts. Catalysts, in their simplest forms, were known to man by the mid-nineteenth century and have progressively improved over the years. Catalysts help hasten reactions and may help in increasing the conversion, thereby reducing the waste; but the catalyst itself creates an environmental problem when it comes out as spent material. Although we cannot do away with catalysts, controlling their use is in our hands.

5.7.1 Definitions

1. A useful catalyst is one which brings about a rate of reaction which considerably exceeds the rate of all other possible reactions.

2. Initiators are substances that usually decompose spontaneously, effectively introducing packages of energy into a small number of reactant molecules to generate reactive species, most frequently free radicals. These propagate the reaction by a chain mechanism.

3. Co-reactants are the added substances and can be referred to as co-oxidants. They are always consumed in the process. For example, bromide or peroxide ions.

4. Inhibition is an occurrence, which implies that a reactant or important intermediate has been removed by a competing reaction with, or catalysed by the inhibitor (occasionally by complexion).

5. Catalyst life and poison is the loss of activity. It is an inherent and an inevitable consequence of the chemical nature of the catalytic material, reactants and products, the result being 'poisoning'. By catalyst 'poison' we normally mean materials which do not form part of the defined process chemistry, but which gain entry into the reaction mixture and lead to permanent or temporary catalyst deactivation. In general, poisons are impurities in the chemical feed-stocks or corrosion products from the material of vessel construction. The product of metal corrosion so introduced may lead to progressive neutralisation of an acid catalyst, or otherwise interfere with catalyst performance; metal ions may also catalyse undesirable side reactions. That is why raw materials should be pure and corrosion should be checked.

5.7.2 Types

1. Some catalysts are homogeneous with the reactants. In homogeneous catalysis, a major problem is the separation of reaction products from the catalysts so as to have an efficient recovery process without impairing catalytic activity.

2. If the catalyst species is heterogeneous, then it simplifies the separation from the reaction mixture, but without drastically changing the nature of catalyst species or its immediate environment. The solid resin catalyst may prove less corrosive to the metal walls of an industrial reaction vessel. Heterogeneous catalysts contain three components namely, major (or primary), minor (or secondary) and the support. Minor (secondary) components are introduced to modify the crystal structure or electronic properties of the major (primary) component, to improve activity, selectivity or thermal stability.

3. Envirocats (environment-friendly) are non-toxic catalysts. They can be easily reused, do not pose disposal problems, often times do not require solvents (hence there are no or low unwanted side products). They filter out with ease and leave no metallic residues in the product.

4. Enzymatic catalysts are relatively new entrants in the field that are becoming popular.

5. Existing/conventional catalysts are aluminum-clay based. (Incidentally, aluminum has possible links with Alzheimer's disease). They are now improved with pores so small as of molecular dimension/shape selective and sites dispersed over surface and pores. Shape selectivity is higher in zeolite materials. Larger number of pores of molecular sieves are in clay materials resulting in better combinations. The advantages of using molecular sieves and related support reagents in organic synthesis are:

- Improvements in the rate and/or selectivity of a reaction compared to conventional conditions.
- Ease of handling and use of generally non-toxic materials (active sites are generally located internally).
- Good thermal and mechanical stabilities (compared to organic/polymer based materials).

- Reactions are usually carried out in non-polar solvents or in the absence of solvents.
- Ease of product and reagent recovery (the materials can be filtered from the reaction mixture and can often be reused).

5.7.3 Operation mode

In the operation, the powdered catalyst must be recovered subsequently by settling, filtration, centrifuging, etc. The efficiency of this recovery process depends on particle size. Alternatively, a fixed bed tower or an expanded bed or trickle bed configuration can be considered. When all reactants and products are gaseous under the reaction conditions, the fixed bed is frequently adopted. But the size diameter depends on whether the reaction is strong exothermic or strong endothermic.

Table 14: Catalytic reactions

Reaction	Example
Acid catalysed	Esterification/catalytic cracking/alkylation of benzene
Hydrogenation	General olefin aromatic/desulphurisation
Dehydrogenation	Ethyl benzene to styrene/isopropanol to acetone
Dual function (acid-catalysed reactions with hydrogen transfer)	Isomerisation of alkanes
Other metal-catalysed	Oligomerisation of C_2H_4/ polymerization of C_2H_4
Oxidations	C_2H_4 to acetaldehyde, C_2H_4→ ethylene oxide
Carbon monoxide chemistry	CO + H_2 → paraffins, CO + olefin → aldehyde

Catalyst deactivation: The activity of any catalyst declines over time. Ultimately the conversion of reactants or production rate kinetics reaches an unacceptable level or a compensatory temperature increase degrades the selectivity. The reasons for this are:

- Particulate catalysts can wear out and fracture through the collisions among themselves, or with reactants, with vessel-wall and fittings (this is called attrition).
- Dissolution or volatilisation of catalytic components takes place.
- Sintering in high temperature gas phase reactions; or

- Slow deactivation if certain impurities are present in the chemicals used for catalyst preparation.

Some industrial catalytic systems in vogue are (see table 14):

The best catalyst in operation mode is that which:

- improves reaction sensitivity by selection;
- is less toxic;
- is solid (for ease of separation);
- is environmentally benign;
- has high surface area, providing large numbers of active sites;
- has physical irregularities like pores, cracks, edges (where reactivity and some times selectivity can be enhanced); and,
- has complex surface chemistry of acid and base sites (and sometimes presence of exchangeable cations).

5.7.4 Case studies

A few case studies as reported in seminars are cited in table 15:

Table 15: Case studies

#	Product	Defects of previous catalysts	Merits of new catalysts
1	Benzylation	Low conversion, high waste generation	The p-benzyl biphenyl is produced by benzylation of biphenyl, using 'Envirocat'. Nearly 100% conversion is achieved, with para to ortho ratio, greater than 3 : 1. Quantity of unwanted polymeric by-product became low, and the catalyst could be filtered out and recovered/reused for 10 repeated uses.
2	Benzolation	Excess raw material above what the stoichiometry needed. Catalyst came out as vast aqueous aluminium effluent.	4-chloro benzophenone is produced by 4-chloro benzoyl chloride + benzene in presence of 'Envirocat' catalyst. It gave more than 90% yield, there was no need of solvent, no excess reagents to begin with are added, and catalyst was regained by simple filtration and reused.

3	Oxidation	This 'Envirocat' is a non-toxic, alumina based, and reusable catalyst.	The solvent use is eliminated. Batch-size, therefore, becomes bigger. Catalyst could be isolated by filtration. Product is recovered by distillation. Almost no waste remains. (Examples are oxidation of ethyl benzene to acetophenone or oxidation of diphenyl methane to benzophenone).

5.7.5 Transporting chemicals

While transporting chemicals or other hazardous materials, the industry must take the following precautions:

1. MSDS of all items must be known. This information should be circulated among both on-site and off-site people. All must be trained in advance in procedures as per supplier's instructions.

2. For managing any spill or leak, first decide whether it is small or big.

3. Put out any open flames or sources of heat or ignition in the area. Workers dealing with the spill or leak must have protective personal equipment. Send non-essential persons away.

4. Local dyking, *in-situ* neutralisation, containing, arresting and collection should be scheduled.

5. For warning fellow road-users, placards are required to be exhibited at safe distance which depends on the potential impact area of the hazard material. See table 6 for suggested safe distances:

Table 16: Safe distances for hazard spill area

Hazardous Materials class	Impact area
Combustion liquid	800 m. all directions.
Flammable liquid	800 m. all directions.
Flammable solid	800 m. all directions.
Oxidizer	800 m. all directions.
Non-flammable compressed gas	Downwind 2100 wide x 3200 m long
Flammable compressed gas	800 m all directions
Poison	Downwind 300 m wide x 500 m long
Explosives	800 m all directions
Corrosive	Downwind 800 m wide x 1100 m long

6. Once the area becomes safe, then declare it so.

The usual precautions like TREM-card and colour-coded hexaplicate manifests and labelling shall be done as per the rules.

6

SUCCESS STORIES

In the earlier chapters, we have seen that WM starts from a common sense approach and travels upwards to the use of complex state-of-the-art technologies. In this chapter, we share with our readers experiences of industries in India and elsewhere that have successfully attempted WM strategies, in the hope that our readers will be inspired by these stories.

We shall also introduce the MPCB's own waste minimisation proposals and strategies.

6.1 Replacing Hazardous Substances

6.1.1 Phenol

It is very commonly used in many industries due to its excellent nature as a combiner. However, phenols also have objectionable toxic, poisonous characteristics. These can target liver and kidney systems, its mal-effects are seen on the skin and it has several entry routes to the human body like inhalation, ingestion, absorption and contact. Thus, the use of phenol must be restricted. This can be attempted by:

1. Materials change: The manufacturing process for traditional fibreglass insulation products utilises a thermo-setting phenol-formaldehyde based resin or binder. By themselves, glass fibres will not stick together. Hence, an adhesive (called a binder) is sprayed on the fibres which are then cured in an oven. This results in corresponding releases of ammonia, formaldehyde and phenol. Recently a new acrylic-based binder has been introduced, with reduced toxic releases.

2. Hardware improvement: A chemical manufacturer upgraded the packing in two phenol stripping columns and was able to reduce effluent generation substantially. In the extractive distillation column, the packing was replaced with graphite trays. This change decreased the amount of phenol in the wastewater and phenol intake.

3. A producer of phenol and phenol derivatives found that his industry was generating phenol-bearing effluent from the bisphenol plant. In order to recover phenol, the industry studied a number of parallel technologies which are summarised as follows:

- Distillation was found infeasible as distillate phenol stream was too high in water content.
- Membrane technology was found to be highly expensive.
- Adsorption, using either a resin or activated carbon was potentially feasible but not selected due to operational concerns and both capital and working costs.
- Liquid-Liquid extraction: Cumene, used with a caustic wash to recover extracted phenol, proved effective, but the recovered phenol was found contaminated with caustic and with chloride and not reusable as raw material for bisphenol. Thus the operation was found only marginally attractive.
- Finally, the mechanical instabilities of HCl recovery column were targeted for improvement and this was found to be effective.

6.1.2 Acetone

Acetone is another common chemical used in many industries due to its ease of combination. However, acetone also has toxic, corrosive, combustible and flammable characteristics. It affects the central nervous system, liver and kidney systems, skin and entry routes to the body, by inhalation, ingestion, absorption and contact. Thus its use needs to be controlled. This is attempted by:

1. **Materials change**: A factory using acetone to clean tools found that it caused several fires. The management switched to a solvent blend plus water-based detergent. The new cleaning agent was much less flammable than acetone, and whatever remained was treatable.

2. **Good operating practices**: A manufacturer of fibreglass reinforced plastic (FRP) door-window items who was using acetone found that the air emissions of acetone were excessive. He examined operating practices and rectified them as follows: (1) Lids on acetone containers were kept tight always; (2) Acetone was purchased in tote bins to eliminate drums and to reduce spill risk; (3) Spent acetone was collected and distilled daily for reuse; (4) Still bottoms' distillation residue was reused as fillers in new products.

3. **Acetone use avoided**: A manufacturer of eyeglass lenses used acetone to remove abrasive pads from lens grinding tools. In 1,050 lb of acetone, 2,170 lb burr got added. As a result 920 lb became air pollutant and 2,300 lb became hazardous sludge. The operations were re-examined, and it was found that the abrasive pads could be removed by manual scraping only, if done carefully. Acetone use was stopped totally.

4. **Acetone use adopted**: A manufacturer of polyurethane foam (FPF) needed a blowing agent in the process. It was using CFC-111 and methyl chloroform and methylene chloride which are ozone depleting substances. Research showed that acetone can replace these, having lower objectionable emissions, and 60% less consumption.

6.1.3 Pulp and paper

Pulp and paper making are a major industry and have many varieties of raw materials, processes and end products. Some examples of innovations are:

1. Where wood is used as raw material, wood ash which is a source of potash and lime can be used as fertiliser. It contains 6% potassium carbonate, 2% phosphoric acid and 30% lime. A case study of alfalfa grass grown for two years with various doses showed that the pH of the soil was automatically raised from 5.8 to 7.4 and nitrogen level in soil got doubled.

2. On an experimental basis, a bio-pulping process was designed in which microorganisms and enzymes attacked lignin before pulping. It gave encouraging results.

3. On an experimental basis, a bio-bleaching process was designed in which due to the organic depolymerisation of lignin, total chlorine use was reduced by 27%.

4. A manufacturer used to coat his paper with a solvent/heavy metal to increase durability and visual appearance. The coating was replaced by aqueous/heavy metal-free coating and by constructing a steam heated coating storage shed, longer shelf life was obtained. VOC emission levels, fugitive solvent levels, flammability and explosive hazards were reduced and there was more acceptability of product due to lead-free packing.

6.1.4 EPA, Ohio State (USA)

The EPA has disseminated the following information on reuse, recycle:

1. **Gypsum**: Gypsum waste can be reused in several ways, for example, making cement, concrete, road construction, fertiliser, sulphur industry, agriculture, bituminous coal mining, landscaping and biological ETP.

2. **Rinse water as bath water**: An electroplater used ion-exchange technology for recovery by first segregating the plating rinse water and then concentrating and recycling it as plating bath. (Likewise, it is worth examining whether reverse osmosis technology can be used in the sugar industry for concentrating the juice and preparing a syrup).

3. **Fly ash**: Wherever coal is burned, its fly-ash poses a disposal problem, unless it is looked upon as a useful raw material and used for liner concreting. When added to Portland cement in the range of 3 to 9.5%, it is found to result in permeability lower than $1x10^{-7}$ cm/sec and compression strength exceed 400 psig. Liner to landfill site has proved watertight.

6.1.5 US-EPA (Federal)

US-EPA (Federal) compendium EPA/600/R-92/046 (April 1992) has also disseminated information on reuse, recycle as follows:

1. **Printed circuit board plating**: Eliminate rinse tank using unique spray-rinse in a transporter hoist system configuration that passes over plating bath tanks. Rinse only for short duration after immersion. It will now be only 10 gpm instead of 60 gpm. Thus a small size metal recovery plant is required. Also, in place of conven-

tional anode bar-and-hook system, copper spheres are in the anode basket with the anode to cathode ratio being one. Plating is even. Payback period is eight years.

2. **Sulphuric acid anodising system**: A unit using chromic acid-aluminum anodising system for the last 35 years, replaced it with H_2SO_4 anodising system, automated hoists and on-demand bath rinse. Discharge was reduced from 15–20 gpm to 6–8 gpm. Less energy was required in production, less time for process, better precision, less labour per job and a small ETP.

3. **Robotic paint factory**: Manual mixing and hand spraying was replaced with electrostatic spray guns, automatic waste cleaning solvent collection and waste paint was recycled through a still. Paint waste reduced from 42 to 17 TPY.

4. **Advanced reverse osmosis system (AROS)**: Two nickel plating baths were followed by a 'dirty' rinse tank and then 'clean' rinse tank. Countercurrent AROS was used. Permeate was found satisfactory as clean rinse water make-up and concentrate (40—50% plating bath concentrate) was used as nickel-plating bath solution. Payback period is 4.4 years.

5. **Cleaning substitute**: TCA (1.1.1 trichloro ethane) and methanol were replaced by dilute turpene-based cleaner. Heater was added to old ultrasound bath. A de-ionised water system and a heat gun were used for drying.

6.1.6 Defence establishment

A defense establishment took a number of WM steps, as follows:

- Spent abrasive blasting media was used as aggregate in asphalt.
- Spent abrasive blasting media was used as raw material for making Portland cement.
- Physical separation was introduced to recover lead particulate from soils at small-arms practice range.
- Lead-containing wastes were processed in secondary smelter.

On-site solvent recovery: This is done in two ways: either batch or continuous.

- In the batch system, atmospheric distillation methyl ethyl ketone (MEK) is reclaimed. The hardware can support a range of 20 litres to 200 litres per batch. The contaminants were found having lower boiling point than the solvent and ended up in the distillate. Residue was a small fraction of the solvent quantity and was disposed of as hazardous waste. The purity of recycled MEK improved from 78 to 85%. Of the 15% impurity, 5% was water and 10% was paint thinner solvent from where this waste originated.
- Continuous vacuum distillation methylene chloride (MC) is suitable for solvents with boiling point up to 80 ^{0}C. The residue at the bottom has less than 5% solids.

Table 1: Environmental concerns

Process step	Area of concern	Probable impacts
Delivery area	Unpaved roadways Drums being stored in trailers	Fugitive emissions Fires and explosion
Drum storage	Poor housekeeping No containment	Runoff Leachate into ground water
Emptying drums prior to incineration	Improper containment Uncovered containment	Runoff/leachate problem Source of fugitive VOC emissions
Drum reclamation furnace (incinerator)	Improper operation (i.e. start-up, shut-down and malfunction)	Visible emissions, excess toxic emissions, excess particulate emissions.
Reconditioning plant	O & M of bag house serving short blasting operation Drying ovens O & M Spray booth O & M Process water	Visible emissions. Excessive particulate emissions. Excessive emission of VOC Excessive emission of particulate Spills going into storm drains. Effluent discharge not being properly treated. Sludge disposal from clarifiers.

6.1.7 Drum reclamation

Drums, barrels and containers are used in all industries to send out their finished products. These drums can be either purchased

afresh or second-hand or they can be cleaned, reconditioned and re-used. The drum processing impacts are tabulated in table 1.

Table 2 lists some improved technologies, some already in existence, others at advanced R&D stage – all collected from various workshops.

Table 2: Improved technologies

#	**Producing**	Previous process	Modernised process
1	Hydroxylamine	Wastewater contained substantial neutral salts.	Catalytic hydrogenation of nitric oxide made in sulphuric acid. Only small amount of neutral salts is formed.
2	Methacrylic acid (for acrylic glass)	Produced from acetone and hydrogen cyanide and cyanhydrine formed as intermediate. When hydrolyzed to get the product, by-product ammonium sulphate also formed in larger quantities than the product.	Started from methacrolein. Oxidized it to get product. Ammonium sulphate avoided.
3	Tert.-Butylamine (for rubber-chemicals and pesticides)	Produced from isobutylene by reaction with formamide as intermediate. Equal amount of sodium formate by-product obtained.	Produced by direct reaction of isobutylene with ammonia, in presence of a catalyst, giving an excellent yield and avoided by-product.
4	Paraffin purification (for pharmaceutical and food industry)	Complicated multi-stage procedure using bleaching clay (needing subsequent landfill) and sulphuric acid (needing subsequent incineration).	One step nickel-molybdenum catalytic hydrogenation on a special aluminium oxide carrier. No disposal problems and yield increased by 10 %
5	Phosphate fertilizer	Rock processed with sulphuric acid, gypsum formed (landfilled or discharged with effluent). In second step, phosphoric acid is used on phosphate rock. For making up deficiency in calcium, calcium is separately added.	Nitric acid used instead. Gypsum by-product not formed. Calcium addition avoided.

6	Phthalic acid (for plasticizers)	Obtained by oxidation of oxylene. Large amount of gaseous by-product formed and removed by scrubbing. (burnt using additional fuel).	New process developed. In this by-product is maleic acid (required in plastic manufacturing) and recyclable washing water. (Effluent problem solved)
7	In production of Nylon-6	Cyclohexane oxidized with air to give intermediate anol-anon mixture. Gives out large amount of by-product in water. (incinerated)	The wastewater can give adipic acid (used in nylon-66) and mother liquor oxidized with nitric acid, giving out succinic and glutaric acid (used for varnish), nitric acid recovered (and reused). What remains is only residue (incinerated and heat recovered).
8	Organic alcohol	Alcohol is formed by hydrogenating aldehyde. Aldehyde is formed by reacting long-chain olefine with hydrogen + carbon monoxide (at high pressure and temperature). As a side reaction, saturated hydrocarbons are produced. This was burnt in local power plant.	Instead of burning, this is now used as raw material in stream cracker, saving expensive naphtha.
9	Cyclohexane oxidation	In this process, crude gas gets formed, containing a mixture of acidic organic compounds. For purifying this, sodium hydroxide solution is used.	New process now developed and resulting concentrated caustic solution is burnt with energy recovery. Sodium carbonate sold after recrystallisation.
10	Synthetic gas production.	($CO + H_2$) gas is produced from heavy naphtha, resulting in wastewater with soot and ash. This is filtered and cake sent to landfill	Now this cake is used for dewatering STP sludge. Energy recovered by subsequent incineration.
11	Thermal power plant	Off-gas is desulphurised by scrubbing with milk of lime, but results in 35000 tonnes of gypsum/annum (800 MW).	Now adopted Wellman-Lord process. First step, SO_2 dissolved in sulphite solution, forms bisulphite. Second step, bisulphite thermally cracked again to sulphite + high concentration of SO_2. This SO_2 is then liquefied and has a number of usages.

12	Salicylic acid	Raw materials reacted with CO_2, and forms sodium alkyl salycilate or carboxylate. By adding $H2_sO_4$, salicylic acid is formed. This generated air pollution, phenol fugitives (in process and transport), needed incineration of cake and its residue ash for landfill.	Process improved esp. in alkylation section. Olefin-phenol mix passed through catalyst-bed. Crude alkylate is liquid, without any solids (thus no filtration, no cake, no incineration, no landfill). This is distilled to get back phenol for reuse. Catalyst regenerated in-situ by burning out carbon coating and reused (once in a while replaced, sent to landfill). Total loss came down to 80 tpa from 420.
13	Polypropylene production	Slurry process: propylene reacted with slurry of polymer and solvent. Three work-up steps required namely (1) remove excess unreacted propylene for reuse, (2) remove catalyst in decomposed form, (3) recover and clean up solvent. All this generated wastes and required high energy for production.	New liquid propylene polymerization process coupled with super high activity catalyst LIPPSHAC used. Advantages: (1) catalyst decomposition, slurry washing, solvent removal, solvent recovery, solvent residue, drying step no longer required; (2) losses of polypropylene to unwanted atactic polymer saved which was 2-3 % of intake; (3) utility consumption significantly reduced; (4) process chemicals are no longer used and their decomposition products avoided; (5) 75% energy saved as also the corresponding air pollution.
14	Benzylation	Low conversion, waste generation	p-benzyl biphenyl produced by benzylation of biphenyl, using Envirocat. Nearly 100% conversion, para : ortho ratio > 3 : 1, low unwanted polymeric by-product, catalyst filtered-recovered-reused till 10 uses.
15	Benzoylation	Excess raw material above stoichiometry needed, catalyst coming out as vast aqueous aluminium effluent.	4-chloro benzophenone produced by 4-chloro benzoyl chloride + benzene in presence of envirocat. >90% yield, no solvent used, no excess reagents to begin with, catalyst regained by simple filtration.

16	Oxidation		This envirocat is non-toxic, alumina based. Reusable. Solvent use eliminated. Batch-size becomes bigger. Catalyst isolated by filtration. Product recovered by distillation. Almost no waste. (examples: oxidation of ethyl benzene to acetophenone or oxidation of diphenyl methane to benzophenone.)
17	Acid or alcohol salt	R-OH + $SOCl_2$ = R-Cl + HCl + SO_2. where R-OH is acid or alcohol. HCl and SO_2 gases are absorbed in caustic soda. Effluent formed.	Two stage absorption possible, and reusable effluent formed, namely commercial grade HCl acid and absorbing SO_2 in caustic soda producing sodium sulphite solution.
18	Vacuum pump water	In the past water used to be once through, thinking this as good uncontaminated water	Analysed the cooling water. There is risk that amines are escaping. Thus recycling a must [apart from water saving, a chemical saving]
19	R-NH-R1	RCl + R1NH_2 + NaOH → R-NH-R1 +NaCl + H_2O. Here separation [purification] of salt and product necessary. Done by adding solvent which dissolves product, but not salt. Salt filtered out as waste (as solvent-damped cake not useful). Solvent distilled to get product. Solvent lost.	Instead of chemical technology, physical technique can be applied for separation (whatever suitable – electrodialysis, ion exchange (by resins), liquid ion-exchange, reverse osmosis, etc). No solvent, no product loss in solvent, no solvent-damped salt, no energy
20	2-chloro-5-nitrotoluene-4-sulphonic acid	Traditionally three steps (sulphonation, chlorination, nitration) are done in one reactor consecutively. Found a number of side reactions and 11 by-products. Thus 60% yield. 40% loss.	Done in three reactors. Raw material consumption reduced 50%, waste reduced 75%.
21	Pharmaceutical intermediate	Organic acid is converted into amide via phosphoric trichloride. Side-products include phosphoric acid, organic waste and large amount of salts.	New reaction path found. Now only side-product is recyclable acetic acid, and easily combustible distillation residue (heat source) and nil liquid effluent.

22	Dyestuff intermediate DNS [dinitrostilbene disulphonic acid]	By oxidizing 4-nitrotoluene-2-sulphonic acid (PNTSA). Oxidant NaOCl is used through reaction medium water. Efficiency 60%.	Oxidant oxygen through reaction medium liquid ammonia as solvent. Yield >90%. Least waste.
23	H-acid	Starting from naphthalene, a number of steps. Finally, for one tonne product, inorganic solid waste 4 t, effluent 68 cum, organic waste one t, and gaseous SO_2, NO_x 0.3 t.	Process changed, integrated waste recycling. Resulted in: • feed reduced from 13.3 t/t to 7.5 t/t • solvent fully recycled • HCl gas converted back to chlorosulphonic acid $ClSO_3H$ & recycled • SO_2 gas purified, liquefied sold out • All wastes reduced by about 50% • Liquid effluent reduced by 80% • Wet air oxidation made on liquid effluent, reducing load by 97% • Waste gas reduced to nil through incineration.

It was found in one industry that waste was reduced by adopting several avenues. Percent reduction break-up contribution was as follows:

- By increasing fuel combustion efficiency, waste was reduced by 1%.
- By destruction/treatment method, waste was reduced by 32%.
- By actually modifying the process reduction, waste was reduced by 1%.
- By adopting recover-recycle technologies, waste was reduced by 9%.
- By adopting new process, waste was reduced by 3%.
- By reviewing the products and production, some units were shut down, resulting in major waste reduction by 54%.

Thus all avenues right from raw materials, utilities and packing should be explored.

In yet another factory, the WMO prepared a list of improvements which it divided into three classes on the basis of economical feasibility and technological reliability. The three categories are as follows:

a) Low capital cost investment

- Recycle vent streams and add additional oxygen.
- Install condenser to remove product.
- Recycle benzene for steam stripper.
- Use steam stripper bottoms as source of water for scrubber.

b) High capital cost investment

- Use superheated steam (as inert gas) and pure oxygen instead of air.
- Replace water scrubber by solvent scrubber.
- Use freeze crystallisation to separate reactants, product and water.
- Purify reactant and product directly from the water phase, rather than by extraction.

c) Cost unknown

- Use fluidised bed reactors (reduce air volume).
- Use new catalyst (better selectivity/ conversion).
- Change air to feed ratio to reactor to reduce gas generation.
- Recover and recycle tars from reactants, product stripper.

6.2 Waste Exchange Oriented Units (WEOU)

Experience has shown that waste exchange can become popular if compatible industries which can mutually use each others' waste as raw material are located together. A stand-alone industry has less opportunity of using its own waste or getting it used by others. However, if there is a cluster of industries, the possibility of using some waste product, by-product, intermediate product or even discarded product as raw material for another industry/industries, within the cluster increases. This is called the waste exchange oriented unit

(WEOU) approach. WEOU will not only make it possible to minimise pollution, but may even enable an industry to attain zero pollution and sustainable development.

The following industrial complexes are examined below:

1. Sugar mill complex
2. Textile mill complex
3. Power plant complex
4. Paper mill complex
5. Fertiliser complex

6.2.1 Sugar mill complex

This is an excellent example of WEOU. A sugar manufacturing unit produces wastewater, air emissions and solid wastes like bagasse, press mud and molasses. It is possible to use all these wastes, and also the secondary wastes that may be created if compatible industries are located nearby. This is schematically shown in table 3 below.

Table 3: WEOU scheme at a sugar mill

#	Unit	Creates waste	Where waste can be used as input	Resultant benefits
1	Sugar Mill	Molasses	Distillery	Raw material for alcohol
		Press mud	Composting	Filler material for treating distillery waste
		Bagasse	– Pulp mill or – Boiler or – Composting	– Raw material for pulping, or – Fuel for boilers for sugar, distillery and paper units or – Filler material for treating distillery waste.
		Wastewater	As water	Water for sugar-distillery-paper mill and own sugar farm.
		Spray pond overflow	As water	
		Cooling water Boiler blowdown	As water	
		Condensate	As water	Boiler, co-generation

2	Alcohol Distillery	Spent-wash from distillation column	Bio-digester	Produces methane used as fuel for boilers for co-generation, sugar, distillery and paper units. Effluent still remains and is used further.
			Sludge and effluent composting	Raw material to make compost. Compost used on own sugar farm
		Yeast sludge from fermentation vats	Composting	
		Moderate BOD wastewater	As water	Treated in ETP and then water used for sugar-distillery-paper mill and own sugar farm.
		CO_2 from fermentation vats	Scrubbed and bottled	Sale and used as preservative for own farm agricultural produce
3	Pulp and Paper mill	Wastewater	Biodigester	Produces methane used as fuel for boilers for co-generation sugar, distillery and paper units. Effluent still remains and is used further.
			Sludge	Raw material to make compost. Compost used on own sugar farm.
		Recovered fibre	Internalized	Reuse or made own cardboard ancillary
			Sent to cardboard making unit	Sale

4	Boiler cogen-eration	Ash	Compost	Raw material to make compost. Compost used on own sugar farm.
			Road, bricks	Internal construction
		Blow-down	As water	Cooled and water used for sugar-distillery-paper mill & own sugar farm
		High pressure steam	Turbine	Electricity produced is used in all mills, and the resultant low pressure steam used as steam to sugar mill, distillery etc. Excess sold to Government.
		Low pressure steam	Used in mill	The resultant low pressure steam used as steam for sugar mill, distillery etc
5	Office, colony	Wastewater	As water	Treated and water used for sugar-distillery-paper mill and own sugar farm
		Municipal solid waste	Composting	Raw material to make compost. Compost used on own sugar farm.
6	Sugar farm	Sugarcane	Sugar mill	As raw material for sugar.
		Agricultural residue	Composting yard	Raw material to make compost. Compost used on own same sugar farm.

Summary:

1. The net waste is nil.

2. Products for sale are sugar, alcohol, paper, liquid CO_2, agricultural produce, cardboard, compost and electricity.

3. Waste products for internal use are bagasse, press mud, molasses, ash, yeast sludge, municipal solid waste, wastewater (sewage and effluent), agricultural residue, sludge, pulp-fibre.

4. Products for internal use/reuse are treated water, bio-compost, methane gas, agricultural residue, liquefied CO_2, sugar cane, electricity.

6.2.2 Integrated textile mill complex

Like the sugar industry described above, another agro-based industry of significance in India is the textile complex. If a raw cloth

goods, fine textile, dye and cotton growing can be combined, there can be waste exchange internally. Wastewater is treated and used in the fields to grow cotton. Kier wastewater (NaOH), mercerising wastewater (NaOH), can be reused. Dye wastewater can be sent for dye recovery and the dye so recovered can be used in-situ.

Summary:

1. The net waste is nil.

2. Products for sale are finished fabrics.

3. Waste products for internal use are wastewater (sewage, de-size effluent, kier wastewater [NaOH], mercerising wastewater, bleaching wastewater, dye wastewater).

4. Products for internal use/reuse are treated water, fertiliser, raw cotton, dye, NaOH.

6.2.3 Fossil-fuel power plant complex

With growing population and its rising standard of living, both at urban and rural places, the demand for clean energy sources, especially electricity, is ever increasing. At the same time, no community wants a thermal power plant in its vicinity. A solution is possible with a WEOU formula. Here a thermal power plant, cement plant (needing calcium sulphate of desulphurised mass) and concrete aggregate or building block plant (needing dust of ESP, cement and treated waste water) can co-exist together.

A thermal power plant creates water and air pollution problems.

(A) Water used at many places becomes wastewater (table 4):

Table 4: Waste streams from thermal power plant

Waste station	Waste stream
Cooling system	Either once-through or recirculating
Wet ash handling	Fly-ash pond overflow and bottom ash pond overflow
Flue gas scrubber	Solids pond overflow and periodic blow-down
Boiler	Blow-down
Evaporator	Blow-down
Other	Ion-exchange, softener, regeneration, filter backwash, clarifier, lime softener blow-down, air pre-heater, boiler fire side wash water.

(In addition to the above, there will be colony sewage, garden return water, fire-fighting drill water, etc.). It is found that this water is not highly contaminated and so, if cooled, settled and given marginal treatment, can be reused.

(B) Coal that is burnt creates air and solid waste in the form of ash, slag, powder.

- Bottom ash, fly ash and slag have about 60 percent silica, 10 to 35 percent alumina, 5 to 35 percent ferric oxide, 1 to 20 percent calcium oxide, plus minor metals, carbon and boron.
- Flue gas desulphurisation creates solid waste by absorption of SO_2 on lime, limestone, as

Lime $SO_2 + CaO + ½ H_2O \rightarrow CaSO_3.½H_2O$

Limestone $SO_2 + CaCO_3 + ½ H_2O \rightarrow CaSO_3.½H_2O + CO_2$

It is found that the calcium sulphite so formed may become useful for cement making.

Portland cement manufacturing needs as additive 2.9% calcium sulphate. It also needs fuel, electricity, water, limestone, shale, gypsum. Concrete block making needs both dense and light weight aggregate. Dense material is sand, gravel, crushed rock, slag and light ingredients will be pumice, furnace clinker, foamed slag, expanded clay, shale, slate and waste ash. A laboratory test of the characteristics of concrete made with traditional light weight aggregate (like pumice, expanded clay) compared with that made with thermal power plant waste and coal-ash, shows that the density of concrete made out of sintered pulverised fuel ash is 40% higher than the pumice-based one, compressive strength is nearly double and drying shrinkage comparable. It is thus clear that a thermal power plant, cement plant and hollow block plant can co-exist for mutual benefit.

Summary:

1. The net waste is nil.

2. Products for sale are electricity, cement and concrete blocks.

3. Waste products for internal use are wastewater (sewage, boiler blow-down, evaporator blow-down, cooling water purging, stack

SO_2 desulphurisation sludge $CaSO_4$), fly-ash, bottom ash of boiler, dust from kiln.

4. Products for internal use/reuse are electricity, cement, treated water.

6.2.4 Pulp and paper mill complex

Pulp-paper mills create substantial wastes and have earned a bad name for poor handling of such wastes. Hence many factories are closing down or winding up production. The problem is not going to get minimised unless a WEOU formula is attempted. Here, a wood pulp mill (giving out bark, sulphite waste liquor and pulp respectively to steam plant, road making and paper mill), a pressed hardboard unit (surviving on waste fibres and sulphite waste liquor binder) and a low grade wrap paper plant can co-exist.

Summary:

1. The net waste is nil.

2. Products for sale are fine paper, pressed hardboard, low grade wrap paper, road binder and concrete blocks.

3. Waste products for internal use are sulphite waste liquor, fillers and fines, tree-barks, wastewater (sewage, boiler blow-down, evaporator blow-down, cooling water purging), fly-ash, bottom ash of boiler.

4. Products for internal use-reuse are sulphite liquor, steam, treated water.

6.2.5 Fertiliser-cement plant complex

This is another example of give-and-take, with fertiliser plant and matching cement plant. The other attendant units could be sulphuric acid plant (for captive use).

A phosphate fertiliser plant needs washed, screened $Ca_3(PO_4)_2$ rock and H_2SO_4. The phosphate rock gypsum waste can go to an adjoining cement plant which will produce cement, dust waste, scrubbed SO_2 and hot water respectively which is useful in fertiliser plant and acid plant. Acid will be needed for fertiliser plant as a raw material reactant. Thus the cycle of WEOU is complete.

Summary:

1. The net waste is nil.

2. Products for sale are fertiliser, cement, water and bio-compost.

6.3 Refineries

(A) Steps for SO_2 emission reduction:

- Use of low sulphur liquid fuel in furnaces.
- Use of gas (nil hydrogen sulphide) as fuel in the gas turbine.
- Amine treatment of fuel gas for removing hydrogen sulphide gas.
- Installing a sulphur recovery unit with 99% efficiency.
- Continuous stack monitoring system (CSMS) installed on all major stacks.

(B) Steps for NO_x emission reduction:

- Use of low NO_x burners.
- Installing thermal deNO_x system.
- To control lead pollution in ambient air fully from motor spirit, installed Methyl tertiary butyl ether (MTBE) unit for manufacture of oxygenates to replace tetra ethyl lead (TEL).

(C) Steps for VOC emission reduction:

- Conversion to internal floating roof in hydrocarbon tanks.
- Conversion of all storage tanks with external floating roofs and additional internal floaters to tanks with fixed roofs to reduce fugitive emissions.
- Providing secondary seals to reduce fugitive emissions in naphtha/spirit tanks.
- Use of double mechanical seals for critical pumps of LPG and light hydrocarbons.
- Pressure relief valves of columns and vessels are routed to flare to avoid fugitives.

- Leak detection and repairs programme implemented using portable hydrocarbon detector (quarterly);
- Installed and commissioned benzene vapour recovery system at benzene lorry loading facility;
- Reduce HC emissions by replacing existing atmospheric blowdown stacks which discharge directly to the atmosphere with flares (being finalised).

(D) Steps for solid waste management and minimisation:

- Mechanical recovery of oil using hydrocyclones in crude tanks.
- Hydrocarbon recovery from oily sludge *in situ* from crude tank.
- Processing of bituminous oily waste, LSHs, waxy sludge to recover oil using strainers and hydrocyclones.
- Bio-remediation carried out on oily earth using bacterial technology (oil zapper), converting oily earth material into CO_2 and water.
- Spent cobalt-molybdenum catalyst recycled indigenously.
- Replace the present particle collection equipment (cyclone) by ESP which captures fine catalyst particles generated by a petroleum cracking unit.
- Sale of oily sludge to micro-crystalline wax manufacturers.

(E) Steps for ETP improvements:

- Eliminate secondary biological and chemical sludge generation from ETP, which comprises of powdered activated carbon treatment (PACT) and wet air regeneration (WAR). The spent carbon from PACT is regenerated in WAR and returned to the PACT unit.
- Reduce secondary emissions from the refinery effluent system by laying a pipe to carry hot desalter effluent water directly to ETP instead of draining it into the process wastewater sewer which is ventilated to the atmosphere.
- Sweep the roadways and concrete areas and install sewer boxes designed to reduce soil movement into the sewer sys-

tem; soil in the sewers not only increases the mass of solids in the wastewater sludge but also makes hydrocarbons that adsorb onto the soils more difficult to treat.

- Reduce secondary emission by installing above-grade pressurised sewers (planning stage).
- Segregate storm water and process water.
- Replace API separator, a part of ETP system that is presently uncovered, with a covered gravity separator and air floatation system to reduce secondary emissions and capture HC vapours (planning stage).
- Current sampling lines are open-ended; when flushed prior to sampling, they increase sewer loading; replace existing sampling stations with flow through sampling stations to reduce the oil loading in the sewer and oil drained to the deck (planning stage).
- Refinery sour-waters typically are wastewaters containing NH_3 and H_2S – these gases are typically removed from the water and purified in a sour-water stripper; the H_2S can cause odour problems, so this improvement would upgrade the sour-water stripper to reduce H_2S emissions (planning stage).

6.4 Case Studies

A few industries that have taken up a WM programme were requested to respond to a proforma questionnaire. The information they were asked was regarding company profile, formation of a Waste Minimisation Organisation, subsequent achievements, etc.

We give below the responses received from a few companies:

6.4.1: M/s Nova Dyestuff Industries Private Limited, GIDC Pandesara, Surat, Gujarat.

1. *Company profile*

The group has conceptually existed since 1977 as a trading firm. It has a dyeing house since 1983 and was incorporated in 1987. Its present name and style are since 1993. It has expanded twice. The number of products now on anvil is 97 disperse dyes, 200 TPM.

Product mix is possible as combination of (1) raw materials to intermediates for sale; (2) raw materials to intermediates for self-use finished products; and (3) intermediate to finished products.

The company employs staff with doctorates, post-graduates, graduates, technical/management graduates, others like ITI-diploma holders and trained workers. The R&D wing as well as periodic inspections from the Department of Chemical Technology, University of Bombay, help both in production improvement and pollution prevention. Sophisticated laboratory is established within the industry which has GC, HPTLC, UV cabinet, Karl Fischer apparatus and many attendant units, glassware and reagents. IT based design software is also used. For environment, safety, occupational health and fire fighting, expert consultant firms in the field are retained to guide the internal environment management cell.

2. ***Waste minimisation organisation (WMO)***

The industry is located within the Government approved industrial estate. It is in the midst of 365 industries and is not in a sensitive residential area. Of the production, 80% is consumed within the city itself and as such there is extremely limited transportation risk. A WMO was first formed with a dedicated chemical engineer heading the team. The team attended the training workshops whenever conducted in the vicinity. A timetable was fixed for designing a programme and budget was earmarked. The driving forces were many, such as necessity of (1) keeping air pollution low, being located in the city; (2) keeping the effluents low having no more land for disposal; (3) keeping solid waste quantity low, it being a costly and risky affair to transport and hand over to a common facility; (4) keeping raw material inventory low, the market being less paying; (5) keeping in line with Gujarat Pollution Control Board policies; (6) seeking MoEF permission for expansion; (7) remaining inside the Charter 2003 CREP regulation; and (8) keeping in line with corporate planning which goes beyond mere compliance of law.

3. ***Achievements***

The WMO designed and implemented some (A) process changes and some (B) hardware changes successfully. These are briefly set out in tables 5 and 6**:**

Table 5: (A) Process changes

#	Station	Present	Changed to	Advantage
1	Product washing	Ample water is used (one step only)	Two steps. Step 1: Use compressed air Step 2: Use limited water	A-1, B
2	Stabilisation, Purification	Reslurry the cake, heat 40-50 degree C and filter	R & D for specificity of temperature duration, colour-wise.	C-1, C-2, E
3	Product changeover	For cleaning the equipment use H_2SO_4, emulsifier, acetic acid and solvents	Campaign management. Avoid radical changes like Blue to Yellow. Instead plan changes from Yellow to Green – Yellow to Orange to Red to Violet to Blue	A-1, A-2, C,E
4	Ethyl pyridone process	Mother liquor of acid nature produced	Isolation not done in process. Zero discharge	A
5	Bromination plant	Double bromine quantity required and lost as pollutant	Half mole bromine used. HBr formed is oxidized in-situ to get back bromine	A-2, A-3

Table 6: (B) Hardware changes

#	Station	Present	Changed to	Advantage
1	Coupling reaction	Diazo enters reactor fitted with old blade stirrers. Slow reaction, thus excess chemicals.	Hi-speed whirlpool agitation with baffles. Instant reaction and observation	A-3, B-2, C-1, D
2	Sand milling	Common sand used, cooled by chilled brine	Special sand, engineered modification, cooled by cooling tower.	A-3, B-3, C-1, E
3	Spray dryer	Plunger pump	Triplex pump, uniform pressure, high average, high solid contents	A-1, B-2, C-2, E
4	De-watering	Nutsche used	Replaced by filter press	E, Z

5	Ammonia recovery in Lueco 14 DAAQ	Liquor ammonia used as raw material and as reaction media. Excess goes waste	Ammonia recovery plant installed	A-3, B-3
6	Solvent recovery unit	By fractional distillation at 50% recovery	Efficient hardware makes it 70-75%. Semi-solid sludge taken for another recycling plant. Released hot, melts quickly, solidifies and incineration proposed	A-3, B-1

Advantages legend

A-1 = Less water use	A-2 = Less wastewater	A-3 = Less raw material use
B-1 = Less product loss	B-2 = More yield	B-3 = Less waste strength
C-1 = Better product	C-2 = Less discards	
D = No by-products, no decomposition products		
E = Less time, more batches		
Z = Pump for feed more convenient than vacuum. Possible to aerate cake. Use of steam/hot water possible.		

4. *Additional points*

- Documentation is now disciplined.
- Monitoring by third party of both ambient and work zones is regular.
- Job satisfaction to the WMO team.
- Learning curve improving.
- Inventory more controlled and now trim.

6.4.2 M/s. Gharda Chemicals Ltd., Maharashtra Industrial Development Corporation (MIDC), Dombivali. Maharashtra

1. *Company profile:*

This ISO 9001-2000 company was established in 1967 and has grown to a Rs.750 crore (US$170 million) company employing about 2500 people in four factory sites and exporting more than 60% of its

output all over the world including USA, Europe and China. About 250 scientists and engineers work in its R&D department. In order to win and retain an excellent core of talent in terms of competency development, knowledge application and action learning, the 'Gharda Institute of Technology' is being planned in the vicinity, over 85 acres. The company's present activities are in agrochemicals, high performance pigments and polymers.

2. *Waste minimisation organisation:*

Gharda Chemicals Ltd. launched its mission in the direction of reduction, recovery, recycle and reuse of its unreacted raw materials, intermediates and products/by-products so as to minimise the waste generation because otherwise it was impossible to achieve total treatment of effluents as required by the statute. This mission was achieved due to persistence and by investing more than Rs.1.2 crores. There was full management support to consolidate the efforts of the WMO. After the initial brainstorming session, three avenues were selected, namely: (1) process change; (2) hardware change, and (3) change in operations.

3. Achievements

(i) Waste minimisation by process change (table 7)

Table 7: Process changes for WM

Sr No	Effort	Effect
1.	Change in process of tetra chloro butyro nitrile (TBN) preparation for the production of CMAC	Reduction in residue and increase in the yield of TBN. Waste was reduced by 13%
2	Residue of tetra chloro butyric acid chloride (TBAC) is hydrolysed to get TBA now without use of acid or alkali	As acid or alkali is no more used for hydrolysis, TBA molecules are not getting destroyed during hydrolysis and thus can be recycled back in the process. TBA is recovered and recycled. Saving in raw materials and reduction of COD load on ETP

(ii) Waste minimisation by hardware change (table 8)

Table 8: Hardware changes for WM

Sr No	Effort	Effect
1	New fractionating column using structured packing (height 6 m) is now erected to separate the solvents from the mixture of solvents (methanol, tert-amyl alcohol, o-xylene etc), which hitherto were discarded together.	Pure solvents, 600 kg per day after recovery are recycled in the process. Saving in raw materials and reduction of load on incinerator with subsequent air pollutants
2	Instead of letting the off gases containing SO_2/HCl, these are now scrubbed in packed column supported by bubble caps followed by falling film absorber. The sodium sulphite is no more contaminated with sodium chloride and thus no more an unsaleable throwaway waste (needing oxidation treatment, by air under pressure and vigorous agitation, before disposal). Incidentally HCl no more goes along with SO_2 (needing scrubbing in caustic).	This resulted in generation of pure and saleable sodium sulphite, as well as recovery of usable HCl. Saving in raw material (HCl), production of saleable by-product (sodium bisulphite, and HCl) and reduction of load on ETP.
3	Water ring vacuum pump replaced by ejectors and oil ring vacuum pump operated in closed loop. No waste water. The oil ringed vacuum pump also does not give any waste water	No waste water is any more generated by this change to oil ringed vacuum pump. The load on ETP (both hydraulic and organic) has reduced.

(iii) Waste minimisation by change in operations (table 9)

Table 9: Operations change for WM

Sr No	Effort	Effect
1	Use of live steam (at high temperature) introduced, on cumidine residue and hydrolysed, instead of throwing it out as waste.	We now get free cumidine. Saving in raw materials and reduction of load on incinerator with subsequent air pollutants
2	In CMAC process tetra-chloro butyric acid (TBA) is recovered by selective isolation from the waste stream of 2-chloro cyclo butanone stage.	TBA is now recovered. Saving in raw materials and reduction of load on incinerator with subsequent air pollutants

3	In isoproturon process, di-methyl urea (DMU), an intermediate, which is completely recovered, purified by streamlined operation	DMU is now fully recovered which was previously only 71.7% Saving in raw materials and reduction of load on Incinerator with subsequent air pollutants
4	It was found that in isoproturon process dimethyl urea contaminated water (which was thrown out earlier as effluent to further treat it by biodegradation after hypochlorite pretreatment) can be used back as it is, and arrangement is so done to recycle back in place of fresh water.	No more effluent. Conservation of water and the load on ETP (both hydraulic and organic) has reduced.
5	Recycle of third wash into second wash, second wash into first at (a) nitration stage in IP process and at (b) TBA stage in CMAC process (countercurrent). Earlier, (a) DMU wash was required to be distilled using steam to recover DMU, and (b) In TBA process much water was required for three washes.	a) No more need of DMU distillation and attendant steam Saving in chemicals, the distillation load reduced, steam consumption reduced, boiler fuel and resultant air pollutants saved. b) In TBA process two thirds water quantity saved, without affecting the product quality. Conservation of water and the load on ETP (both hydraulic and organic) has reduced. After recycling of washes, load has reduced by 2.5 KL per day.
6.	Water of steam condensate was going to effluent treatment plant. This was stopped by good operational practice.	Heat of steam condensate became available, as also the cold water through heat exchanger. Conservation of water (both as boiler feed and as cooling tower make-up) with reduced load on ETP. Also conservation of energy.
7	Flash steam was getting let off in atmosphere. This was stopped by good operational practice.	Live steam as well as condensate became available, as also the cold water through heat exchanger. This live steam is used in vapour absorption machine (VAM) to generate chilled water and the condensate is added to boiler feed water.
8	Cooling tower sand filter back wash was going to ETP. This was stopped by good operational practice, namely settling out the suspended solids.	Water becomes available again for further use in cooling tower. Conservation of water (as cooling tower make-up) and reduced load on ETP.

The source control by above three avenues has resulted in total reduction in hazardous waste generation of 1,790 kg/day, total reduction in COD of 128 kg/day and conservation of water of 170 kl/day. Total reduction in COD is 128 kg/day and conservation of water is 170 kl/day.

4. *Upgradation of ETP*

This was done to reduce the load on the tertiary treatment, to accommodate the effluents of the new products to be introduced to the extent of 25% and to get more consistent quality of treated effluent. Salient features of the upgradation are:

- Two stage settling (plain and aided).
- Two stage equalisation (one before and one after primary clarification).
- Two stage oil separation.
- Regular removal of the sludge through a timer based on-off valve.
- A standby polypropylene filter press for dewatering the sludge.
- The effluent treatment plant is totally automated. With the provision of automation at all stages to critically maintain all the parameters at required levels, the possibility of any perturbation in the performance of the effluent plant due to human error is eliminated.

Gharda Chemicals Ltd. has earned job satisfaction both by waste minimisation and ETP upgradation.

6.4.3 M/s Sudarshan Chemical Industries Ltd

1. *Company profile:*

Sudarshan Chemical Industries Ltd., was established in 1952, almost immediately after independence, with organic pigments; it developed the intermediates required as raw materials, progressively indigenously. It later diversified to the agro-chemical field (pesticides). At present, Sudarshan has three manufacturing facilities in Maharashtra, all certified with both ISO 9001 and ISO 14001. Sudarshan was the first chemical company in India to be awarded ISO 9001 certification.

The company has competent technical personnel with doctoral qualifications, also post-graduates, technical/management graduates, ITI and diploma holders and trained workforce. The research and development laboratory is adequately equipped with GC, HPTLC, UV cabinet, fermenter, Karl Fischer and other modern instruments. Advanced design software is available for use for design and development of processes, products and hardware.

2. *Waste minimisation organisation*

Sudarshan is a multi-product and multi-location company. This was possible to achieve because the top management always had a vision of sustainable growth, focused on WM and safe work environment. For fulfilling this purpose, an environment management division was set up. Its team members underwent extensive training for both the purposes of prevention and control of pollution at Radion Corporation, Austin, USA,since 1988.

The WMO team has on the drawing board more than 200 programmes related to product yield, WM (both solids and liquid), savings in utilities (steam consumption, electricity, fuel oil, cooling water, etc.), by-products development and water recycling.

3. *Achievements:*

Some major achievements are listed in table 10:

Table 10: Major achievements

#	Area	Previous	Changed to	Gain
1	Production	Consumption of sulphuric acid in 2003 was 2477 tonnes	By instrumentation, good operation and improved hardware, reduced to 1422 tonnes in 2005.	a, b, c
2	Effluent treatment plant	Consumption of lime in 2003 was 770 tonnes	By reduction in use of acid and acidic raw materials, reduced to 665 tonnes in 2005	a, c, d
3	Effluent substream	Joining ETP for treatment	Converted this substream to serve as flocculant aid, and the same is used in primary clarification to settle out solids.	g, h

4	Effluent treatment plant	No by-product, ending up as load	By-product recovered in the form of usable gypsum, which is 50% by volume (cost involved Rs. 50 lakhs)	c
5	Effluent treatment plant	Treated wastewater not used	Now used for lime slurry making, for floor washing and also in single pass gas scrubber	d, a
6	Production	Starting from raw materials.	Starting from intermediates, with pre-check of quality in laboratory. Solids load decreased by 50%	c, f
7	Production	Spent acid generation of 10% concentration, still labelled as waste.	Spent acid generation of 25% acid concentration, now not a waste but serves as raw material.	a, g, c
8	Production	No recovery system Installed membrane based R.O. system.	Advantageous	a,g,h

Legend for gains

a Less wastewater **b Less raw material use**
c Less solid waste **d Less water use**
e Less solid waste disposal cost **f More yield**
g New resource **h Ease of treatment**

The efforts made have been appreciated by collaborators. Sudarshan received a citation from Chemtech, DMAI, it received ISO 9001 and 14001 certification and generated confidence for OSHAS 18001 and 5 "S" system implementation.

6.4.4 Sandoz Private Limited, Mumbai

1. *Company profile:*

This Novartis group has several branches. Its vision is to discover, develop and successfully market innovative products to cure diseases, to ease suffering and enhance the quality of life. It claims to adopt a precautionary approach in the innovation and development of new products.

2. *Waste minimisation organisation*

A WMO was formed and a White Paper prepared for the brainstorming session. Refresher training session was designed and conducted. Clear, measurable targets were set and incentives on basis of individual target fulfillment were declared.

3. *Methods*

(i) Laboratory process development:

Two processes were developed, one in Cefpodoxime Proxetil and another in Cefixime (both being Cephalosporin antibiotics).

a) Cefpodoxime Proxetil: The process involved use of a catalyst which has a strong organic base and is difficult to treat at the end since treatment means removal of the spent catalyst by forming its salt and filtering it out. As this was cumbersome and handling was dangerous and risky, process change was the only answer. This process change was extraction in aqueous stream. The resultant waste could be made biodegradable by oxidation (Fenton oxidation). Subsequently, Fenton oxidation too was dispensed with by digesting with alkali. There is no more cumbersome or risky treatment needing oxidation. This was implemented on plant scale.

b) Cefixime: There was an intermediate in the existing process. Its quality was such that further charcoalisation step was necessary. This was reviewed and new process was developed. The quality of resultant intermediate improved so much that though charcoalisation was still necessary, the requirement of filter aid and charcoal was reduced to 75%. This not only reduced the hazardous waste generated but also increased the batch capacity. This was implemented on plant scale.

(ii) Process optimisation:

In Cefixime intermediate step loss of methylene chloride was noted to a tune of 65 MT halogenated VOC becoming air borne. A number of steps were taken such as:

- Watch on material and disciplined operation.
- Closing the sampling loop.

- Using chilled glycol in condensers of reactors.
- Using chilled glycol in condensers of solvent recovery (both primary and secondary).
- Using DMF for maximum extraction of methylene chloride from distillation residue.
- pH adjustment in mother liquor tank to reduce exposure.
- Minimising unnecessary sampling.
- Filter bed preparation with water and avoiding use of solvents.
- Leak test of solvent handling circuit.
- Detection of halogenated solvents and heavy metals.
- Installed second collection pot (to enable undisturbed drying operation).
- In critical reactions and in such reactions where water is an enemy, high quality solvents were introduced.
- Segregation principle adopted, i.e, recoverable solvents are not mixed together.

(iii) Hardware changes:

a) To avoid solvent losses – installation of condensers with chilled cooling to crystalliser.

b) To avoid halogenated VOC – instead of direct liquid nitrogen injection, cryogenic temperature is achieved by indirect cooling coil.

c) Chilling of underground tank avoided VOC emissions.

d) Creation of separate space for hazardous waste and quick disposal of the same.

Table 11 indicates the level of success achieved and the areas where improvements are still required.

Table 11: Levels of success achieved

#	Consideration	Aim units [bench-mark] not more than	Actual achievement units	Good, bad or ugly
1	Water consumption	10	16.84	Bad
2	Energy consumption	10	9.47	Good
3	SO_2	10	1.57	Good
4	NOx	10	4.73	Good
5	CO_2	10	5.26	Good
6	Halogenated VOC	10	25.26	Ugly
7	Non-halogenated VOC	10	7.37	Good
8	Non-hazardous waste generated	10	23.68	Ugly
9	Hazardous waste generated	10	18.95	Bad
10	CFC 11 equivalent	10	0.53	Good
11	Lost time acci rate	10	9.47	Good
	Total	**110**	**123.13 Exceeds by 11.94%**	**Good 7 Bad 2 Ugly 2**

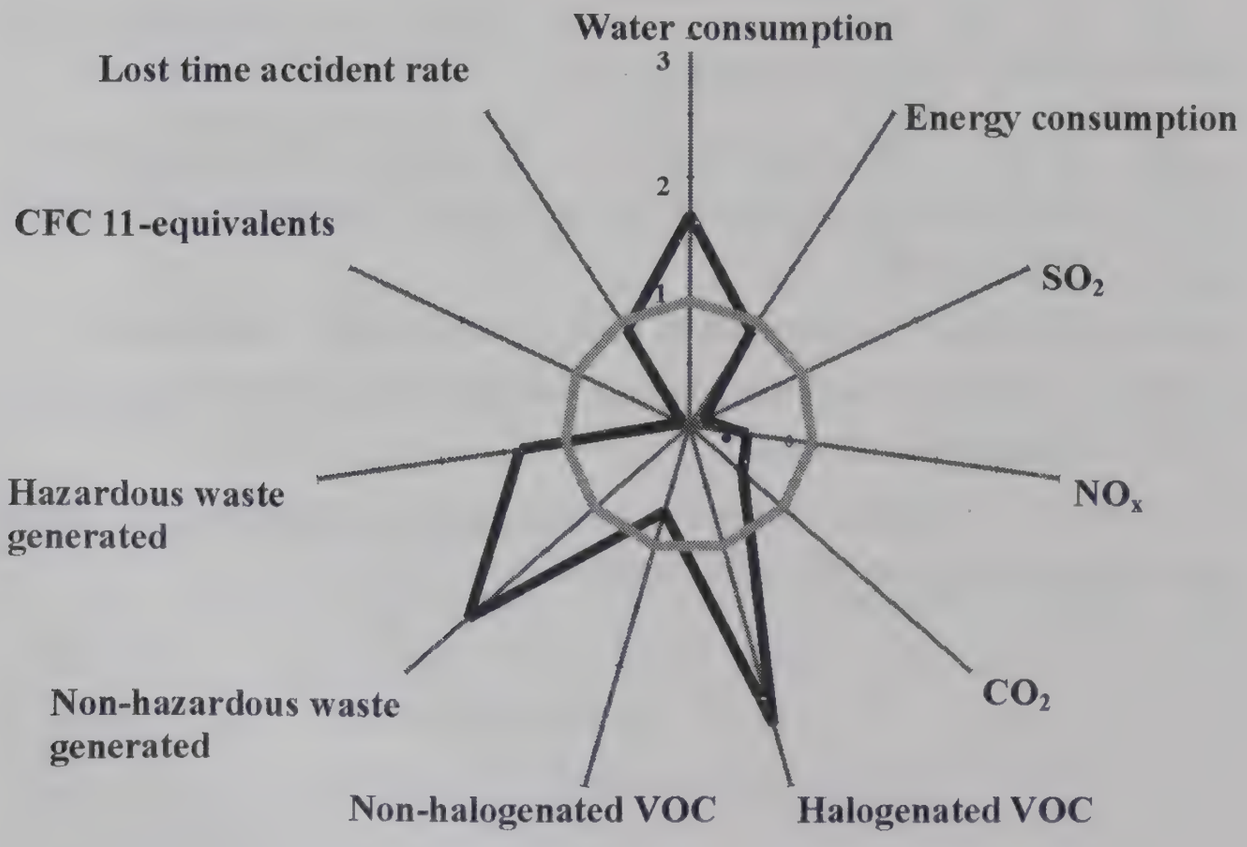


Fig. 6.1 Waste minimisation programme (WMP) of Sandoz Private Limited

4. ***Achievements:***

The company achieved direct results such as (1) SO_2 emission reduced by 40%; (2) change in fuel reduced consumption of fuel; (3) CO_2 emission reduced by 16%; (4) hazardous waste incineration cost reduction by 45% due to less debris.

The company achieved secondary indirect benefits too. The reduced VOC emissions controlled the HAP (Hazardous Air Pollutants), and also helped in – (1) reduction in organic waste load at ETP; (2) increased biodegradability; (3) single step distillation of mother liquor; (4) reduction in energy cost; (5) reduction in batch cycle time; and (6) solvent could be reused in the same process.

5. ***Additional points:***

The other sister units too were inspired to do similar work. Their experiences:

1. **Product separation method changed**: Product is isolated by using chloroform. The aqueous layer after extraction is the effluent. This has high chloroform and fermentation microbe sludge. This was sent to ETP but the load was heavy. To improve this, a solvent recovery plant (by way of stripping chloroform 90%) was introduced and the chloroform stripped effluent only sent to ETP. This reduced the unwieldy load. However, this involved substantial consumption of steam. To improve this, instead of solvent method, separation was tried using super decanter. Chloroform is fully avoided, so also the recovery steam. The centrate is 50 per cent less polluting and has good biodegradability. This is sent to ETP.

2. **COD caught as solid**: The same principle was used to reduce high COD load on ETP, by first catching it in solid form, ahead of ETP. The aqueous waste substream is now pretreated by pH adjustment and then clariflocculated with selected polyelectrolyte. The solids so precipitated are separated by subjecting them to the super decanter. The centrate is degradable and hence sent to ETP.

3. **By-product recovered from effluent**: There was an aqueous organic wash with very high COD (about 150,000 mg/lit, comprising amines, piperazine, DMF and acetic acid). It was decided that instead of sending to ETP as it is, recovery should be attempted.

Vacuum evaporation gave piperazine diacetate – a value-added by-product.

4. **Using solid waste**: In a production step, mycellium biomass is generated after filtration. This is now taken for methane generation in UASB bio-digester. Waste burden is reduced, energy is obtained, mal-odour is avoided. The unit received the global award within Novartis.

6.5 The MPCB WM Programme

6.5.1 Background

Maharashtra was the first state in the entire country to set up a Board dedicated to the prevention and control of pollution. The basis was Maharashtra's Act on the Prevention of Water Pollution, 1969. The preamble of the said Act states that its purpose is the 'prevention, abatement and control' of pollution. Thus waste minimisation or pollution prevention (P2) goes way back in history in Maharashtra. Whatever applies to water pollution, applies equally to other wastes.

As a background to the MPCB WM-programme, the following information may be relevant, namely –

1. A total of 56,061 consents and authorisations have been given to industries and local bodies, while 6,062 authorisations have been granted for bio-medical wastes.

2. A total of 6,956 assessments have been done under the Water (P & CP) Cess Act, 1977.

3. A total of 55,911 industries have been identified which include 15.45% in red, 17.08% in orange and remaining 67.47% in green categories. (The total effluent generated is 6922.7 MLD).

4. Of the water pollution prone industries, 5,987 have adequate treatment facilities, of the air pollution prone industries, 6,637 have adequate emission control facilities, and of the hazardous waste generating industries, 2,960 have adequate treatment and disposal facilities.

5. Of the 872 units covered under the Central Action Plan (CAP), 592 have complied with the standards, 180 units are closed and 100 have not yet complied with the standards.

6. There are 22 CETPs catering to 4,034 units with a capacity of treating 164.35 MLD (2.38% of the total effluents generated).

7. Under Section 33A and 31A respectively of the Water and Air (P & CP) Acts 1974 and 1981, 2184 notices of directions have been issued to obtain compliances with the rules.

In 2004, MPCB surveyed industries in the state and found that work of waste strength reduction was taken up with some seriousness only by a few industries. In the second phase, the survey was restricted to industries generating more than ten tonnes waste per month and storing it for more than 90 days. Though there was reluctance to begin with, lately it is found that as the cost of compliance is mounting, the modern managers have realised the benefit of reducing the use of chemicals resulting in increased wastes. Waste minimisation has also lowered the possibilities of accidents, disasters, unforeseen acts and other such events. MPCB and the generators are increasingly finding it difficult to get suitable lands for waste disposal. The CREP Charter 2003 is thus taken seriously, both by MPCB and the generators. While scrutinising applications for renewal of consent to operate, a simple formula is applied: do the figures given satisfy the equation: total raw materials minus products equals the losses. In other words, are all the figures correctly given, and if not, why not. This commences a dialogue that ultimately leads to the possibility of recovery and reuse. An undertaking is sought that the generator will design a programme to reduce the volume or toxicity of waste to (a) a degree and (b) a time-frame, both voluntarily determined by himself. The State Board's insistence on the CREP Charter 2003 and accurate annual Environmental Statements additionally promote source reduction, recycling and treatment.

6.5.2. MPCB's design of a WM programme

MPCB has framed a policy of technical pull and legal push as a way of assisting industry to achieve compliance with law. The steps that are proving useful for streamlining this process are given in table 12:

Table 12: Steps towards a WM strategy

#	Step	Remark
1	Data collection and analysis	– An intelligent questionnaire – Application for consent renewal – Last two annual Environmental Statements – Annual returns on prescribed forms – Inspection visits
2	Using data to find WM potential mutually	– Comparing the figures of similar kinds of industries. – Reading literature and association seminar documents to note success stories. – Training personnel of industry to realise and accept the need and potential of WM. For this, a group of MPCB officers, enlisted institutes and consultants is formed to go into these issues in depth. Driving force varies. (Officers are being trained for conducting probing inspections.)
3	Industry's voluntary commitment	– Corporates sign agreements that their companies will participate in the WM programme.
4	Assisting the industry with technical information	– Evaluating together with plant personnel opportunities for more WM. – Assuring the industry that consent will be modified to accommodate changes achieved in waste management practices, especially to get by-products. – Encourage the quality circle concept and make available information about WM in other Industries that produce similar products, by-products and wastes. Also maintain a list of waste exchange banks. – Periodically conducting workshops, comparing notes and examples of success stories, and preparing a list of helpful consultants and institutions. – Disseminating handouts, vendors' list, checklists and guidelines. – Conducting waste audits at the request of the district administration or industries and suggesting ways for WM.
5	Removing bottlenecks for the Industry	– Giving revised consents with some concessions (like storages to facilitate recovery, or to use the waste later). – Allowing addition of some by-products in the consented product list. – Change in HW quantity or mode of disposal
6	Review failures and reframe cases.	– Taking stock of the situation and revising the strategy. If necessary, giving legal relief in deserving cases.

The MPCB system is becoming popular with the industry and people alike.

6.5.3. Results

Before the campaign commenced, the responsibility of managing hazardous waste was not taken with as much seriousness as it deserved. The inventories were incomplete, few occupiers were members of any authorised, secured landfill site or had their own incinerators (resulting in illegal waste dumps) and many non-industrial sources of waste were not even examined. When the campaign was undertaken, all the above points were explained and the climate improved in favour of waste minimisation.

As an example, in 2003, the membership of the common facility of TSDF at Taloja site was only 62. After spreading awareness of the legal requirements, the number went up to 1263 (more than 20 times) in a short time span (table 13).

Table 13: Utilisation of TSDF

#	Particulars	2003	2004
1	Membership	62	1263
2	Direct landfill MT	17824	29793
3	Landfill after treatment MT	2443	22766
4	Incineration MT	1081	4681
5	Total waste so managed MT	21348	57240

It was also found that there were unattended wastes either in the form of illegal waste dumps in MIDC areas, or waste stored in closed industrial units or non-industrial sources of waste like the railways, defence, airport, port, docks, state and city road transport undertakings, municipal corporations, MSEB, coal fields, vehicles, etc. All these waste figures are now known and these have become a starting point for reducing those figures. The inventory states:

- Authorised HW quantity MTA = 11,09,241.
- Non-industrial sources HW in MTA = 87,343.
- Illegal waste dumps or waste in closed industrial units MT = 40,950.
- HW from non-industrial sources MTA = 87,343.

- Solids from CETPs MTA = 28,764.

The waste generation is as per the table 14.

It is now apparent (although not so evident in the early stage) that the pesticide making units are only 1.66% of the total industrial establishments of the state, but are producing as high as 21.12% of the hazardous waste. These industries were therefore targeted first for minimising hazardous waste. Many industries agreed to participate in waste strength reduction and then to join the CHWTSDF. A scheme is now developing, commencing 2006, for obtaining firm commitments from these industries for submitting a WM Plan. It is expected that these large employers will use the tools of process modifications, material substitution, segregation and recycling. The aim is 10% waste reduction every year. At the same time, for industries where WM is not presently practised, MPCB's approach is that at least there should be no WI (waste increase).

Table 14: Waste generation in Maharashtra

#	Industry type	Authorisations granted	HW Q MTA
1	Bulk drugs and pharmaceutical formulations	525	82561
2	Dyes and intermediates	211	130410
3	Petrochemicals/Refineries/Oil-processing units	201	95443
4	Pesticides and formulations	76	234309
5	Other chemicals	651	103136
6	Metal reprocessing, finishing and metallic salts	515	113873
7	Resins and adhesives	176	5902
8	Engineering and metallurgical	483	83941
9	Solvent distillation	88	29141
10	Paper and millboard	68	34849
11	Power plant	11	8832
12	Textiles	431	81250
13	Mining	28	2328
14	Paints, inks, varnishes	112	3960
15	Others (sugar, alcohol, rubber, asbestos, fertiliser, etc.)	995	310206

Some examples of success in inventorisation and authorised disposal of waste are cited below:

1. **Refineries**: VOC emission is reduced by converting to internal floating roof in hydrocarbon tanks, use of double mechanical seals for critical pumps of LPG and light hydrocarbons, installing benzene vapour recovery system at loading facility, etc.

2. **Chemical units**: Water ring vacuum pump is replaced by ejectors and oil ring vacuum pump operated in closed loop so that there is no waste water. The oil ringed vacuum pump also does not give any waste water. Another operational trick is the recycle of third wash into second wash, second wash into first wash at (a) nitration stage in IP process and (b) TBA stage in CMAC process (counter-current). Earlier, (a) DMU wash was required to be distilled using steam to recover DMU, and (b) in TBA process a lot of water was required for three washes.

3. **Dyes units**: All the effluent sub-streams were routinely passing to ETP. This was examined. One substream had the potential to convert and serve as flocculant aid, and the same is now used in the ETP itself. By-product is recovered in the form of usable gypsum, which is 50% by volume (cost involved: Rs.50 lakhs).

6.5.4. Prevention is better than cure

The objective is to review the processes of each new industry, encourage a quality circle type mutual aid approach especially for small scale industries (SSI), write common check-in points/do's and don'ts, discipline protocols, discourage indiscriminate landfill over a fixed period, earmark some rolling funds for deserving cases and spend MPCB funds on training needs of persons every year.

Continuing initiatives are:

- Disseminate information to generators, engineers, plant operators on WM techniques.
- Work with individual firms to implement WM methods.
- Encourage industries to share information about WM successes.
- Identify funds and incentives for capital-intensive technologies.

- Assist in overcoming regulatory barriers that impede WM efforts (increasing production without increasing pollution load).
- Ensure that new or expanding industries develop WM plans, *ab initio*.
- Determine HWTSD stations especially designed for SSI.
- Co-ordinate with other government departments like the Factory Inspectorate, Health Services, Transport, Traffic and Law.

6.5.5. Planning

In accordance with law, MPCB is trying to prevent, abate and control pollution and keep our environment wholesome. Some steps likely to be taken in the near future in order to achieve this objective are:

1. Every human activity results in some residual pollution. Therefore, consents issued by the Board permit some discharges within permissible limits. Industry will be trained to ensure that these limits are followed. For example, consent may permit release of effluent of 20/30 standard (BOD 20 mg/lit and SS 30 mg/lit) because it is expected that the stream will offer eight times dilution. Industry should examine whether this is in fact available at the time of discharge. Or, consent may permit to release an effluent of BOD 350 mg/lit into a municipal sewer. While arriving at this it is expected that at the other end it is treated. Industry should examine whether it is so done at the time of discharge.

2. In order to give encouragement for WM, MPCB would like to see industry either generating half the waste quantity while doing the full production or perhaps doubling the production keeping the waste at the original level. This is a part of the technical 'pull' offered by the MPCB, i.e., permitting expansion if there is no increase in the pollution load.

3. At present there are no restrictions on the quantity of material sent to a secured, authorised landfill site. MPCB feels that the time has come for land-ban restrictions to be set out. This may be done in stages, for example. continue the present practice for another two years, thereafter no dioxins and solvents, another year later no met-

als, cyanide, corrosives, halogenated organics and so on, while commencing the discouragement from now on itself.

4. The EA must be viewed by industry as an exercise in self-study where industry can come to terms with its mistakes and make sincere efforts thereafter to design corrective actions. In other words, Form V is like a confession made in good faith which will not be used as a stick with which to beat industry. MPCB thereby intends to persuade industries that they should comply with EA more seriously and transparently discuss the findings with the Board, without fear of prosecution. In fact, if mistakes are identified by the industries themselves, MPCB would like to help them in rectifying these.

5. The EA may bring out the necessity of upgrading treatment. Some Industries may willingly do this, but others try to postpone or justify remaining at the present expenditure level. MPCB has arrived at findings of what percent of total annual turnover an industry should invest in pollution control. MPCB also has on record the funds that the industry has stated will be earmarked for environmental improvement in its application to MoEF. This will be insisted upon and industries will be forced to fulfill their commitment vis-a-vis expenditure earmarked for pollution control.

6. The waste material from industries eventually reaches a common effluent treatment facility/public owned treatment facility/hazardous waste storage treatment and disposal facility/common landfill/community incinerator, etc. How reliable are today's CETPs, POTs, HWTSDFs? If they are not reliable, then we are only concentrating the hazards and making the situation worse than dilution and dispersal. People will rightly lose faith in such disposal facilities. MPCB therefore intends to act as a watch-dog in respect of such common facilities.

7. MPCB is convinced that hazardous waste can be controlled in a state if WM is a constant and conscious goal of industry. A WM programme is most likely to be successful when:

- The Hazardous Waste Rules are implemented in letter and spirit.
- The alibi of membership of a common facility is thoroughly checked.

- Local mushroom incinerators are disallowed.
- Landfill is not taken as the primary solution.
- Working of CETP or HWTSD common facilities are examined and not simply assumed to be in order.
- Illegal dumps are detected.
- Night time dumping is policed.
- Unauthorised auctioning is prohibited.
- No new industry or expansion/diversification is allowed without examining the industry's efforts to reduce and re-utilise the by-products produced.

MPCB's Action Taken Report (ATR) as per Supreme Court directives contains the following information:

1. CETP and HWTSD common facilities have been inspected and defects programmed for time-bound rectification;

2. Discussion on electronic-waste (robots) has already commenced;

3. Hazardous cargo at the airports have been dealt with;

4. Industries operating without authorisation are brought into focus;

5. Inventory of illegal dumps has been prepared. These dumps were found to be:

- Within the same industrial premises, done unscientifically.
- Within the same MIDC or municipal area, using their non-hazardous dumping ground for this purposes.
- Outside of MIDC or municipal limits and also unattended.
- Auctioned out to unauthorised vendors.

6. Bank guarantees have been obtained from a group of industries as a bond of collective good behaviour and failure of one would result in forfeiture of the money by all.

7. A watch dog committee called the Local Area Environment Committee (LAEC) has been appointed comprising persons who have a stake in disciplined working of the industrial group.

8. Industry is kept under pressure not only from MPCB but also from other bodies such as MIDC, MSEB, the district collector, the Water Supply Department, etc.

9. Help is taken from the remote sensing organisation (NRSA, Hyderabad) to locate and identify hazardous waste dumps.

10. MPCB has been strengthened as per directions of the apex court.

MPCB would like industry to be at least ten years ahead of its time, for inventing ideal chemicals like biodegradable detergents or non-CN electroplating, to be vigilant of the laws and standards, and to recognise that while there is no doubt excitement in manufacturing, it is even more challenging to find ways for WM. Industry should try to use control techniques employed in production, for pollution control as well (see table 15).

Table 15: Production techniques for pollution control

Type and explanation	Example
Substitution – Less hazardous chemicals and equipment	Low toxicity solvents Heat transfer through water rather than through oil High flash point chemicals
Attenuation – Use chemicals under conditions that are less hazardous	Use vacuum to reduce boiling point Reduce temperature or pressure Dissolve in safe solvents Prevent reactor runaway reaction
Isolation – Isolate equipment and hazards	Controls distant from operations Strengthen control rooms and tanks
Intensification – Reduce quantities of chemicals	Use small continuous reactors Reduce raw material inventories Improve controls to minimise hazardous intermediates
Enclosures – Enclose equipment/room and use negative pressures	Seal rooms, sewer vents and shielding Remote and continuous monitors

MPCB is thus hopeful of achieving success in keeping the state's environment wholesome. Whether this strategy is adopted voluntarily or under compulsion, it is bound to give good returns with reasonable pay-back for investments made, apart from the good label that industry gets from the surrounding public and its own workers.

7

SAFETY FIRST

7.1 Risks and Accidents

Risk assessment analysis is no longer a luxury preoccupation, since after thought is no longer an acceptable procedure. One has to anticipate risks. Risk is the expected frequency and consequence of possible accidents. Risk analysis is the process of imagining the possibilities that may occur. Risk analysis means answering three questions. (1) What can go wrong? (2) How likely are the chances? (3) What are the impacts? Risk assessment means answering the fourth question, namely, are the consequences tolerable?

There are two types of risks, one arising from accidental releases and the other from routine pollution and wastes. The former demands development of on-site and off-site emergency preparedness plans including accident prevention, evacuation, damage control, etc. Routine emissions involve a steady threat to the environment, safety and human health. Internal accidents may damage company property. However, when either of the two crosses the boundary and occurs beyond the premises of the project proponents, the general public is put to risk. The accident is no more limited to environment, safety or health aspects, but may create a law and order situation. Terms are defined in table 1.

7.1.1 Definitions

The definitions in table 1 imply that a disaster is an emergency event, but not all emergencies are disasters. Two distinct features that make chemical or hazardous waste emergencies and disasters unique from a safety standpoint are – one, the probability of occurrence is low; and two, the consequences could be severe if they do occur.

Table 1: Definitions

Risk	Probability or chance of an undesirable event.
Hazard	An adverse event itself. As per Webster's dictionary, a source of danger.
Incident	Release/spill of material harmful to human life or damaging to the environment.
Event	Incident actually gives rise to loss, injury or some form of damage.
Emergency	Event creates circumstances, calling for immediate action.
Disaster	Event brings great damage, loss or destruction.

7.1.2 Disasters around the world

In Chapter 2, we have referred to a few disasters, to which we add the list given in table 2 below to impress upon all handlers of raw materials and waste materials that proper waste handling and minimisation is the only answer to avoid unfortunate accidents.

Table 2: Chronology of industrial disasters

#	Year	Place	Impact	Remark
1	1945	Chile, Sewel	383 miners died in a flash fire in an underground car repair shop. Hundreds more injured.	
2	1952	UK, London	12,000 died from ingesting smoke, sulphur dioxide, chemical and gasoline fumes.	Deadliest fog
3	1962	UK London	136 people died, 1,000 hospitalised.	London fog
4	1974	USA Michigan	30,000 heads of cattle, 15 lakh chickens and 7,700 other cattle slaughtered, 10,000 pounds of cheese and 15 lakh eggs destroyed.	Feed accidentally contaminated by poly-brominated byphenyl (PBB).
5	1974	USA Mississippi	Millions of chickens destroyed.	Fear of cancer causing dieldrin found in the feed.
6	1971-86	USA Mississippi	All residents of a beach evacuated. Hundreds of animals had died.	Flood revealed such soil contaminated by dioxin waste oil. This was from a pharmaceutical company.
7	1976	Italy, Seveso	Thousands of animals, birds died and hundreds of residents were ill.	Explosion in a germicide making unit released a cloud of toxic dioxin

8	1978-85	USA New York	Children with birth defects. 239 families evacuated, relocated. Chromosome damage feared. Court ordered US$20 million settlement.	Dumping of 21,800 tons toxic waste in 16 acre ditch, including polychlorinated biphenyls, dioxin and long-lasting pesticides.
9	1981-87	Spain, Madrid	Deaths 700, sickness 25,000.	Caused either by cooking oil mixed with rape seed or tomato crop contaminated by organophosphate pesticide.
10	1984	India, Bhopal	At least 2000 died, 200,000 injured	Pesticide, using carbon tetrachloride, methyl isocyanate and alpha-napthol.
11	1984	Mexico	452 people killed, 4,248 injured, 31,000 displaced.	Explosion at a gas storage.
12	1986	Switzerland, Basel	5 lakh fish died in the Rhine river	30 tonnes of toxic chemicals and 440 tons of mercury spilled into the river.
13	1989	Ufa, USSR	190 people killed, 720 injured and another 270 presumed dead	A leak in a liquefied petroleum gas pipeline ignited by a passing train
14	1991	Thailand, Bangkok	3 residents killed, hundreds injured, 6,000 homeless	Fire caused by explosion in warehouse with 23 chemicals

How costly accidents can prove to be can be seen from the experiences of others, for example:

- In October 1987, Monsanto paid US$16 million as damages to 65 claimants on a charge of failure to warn of dangers of a chemical spill that occurred in 1983.
- In 1986, Monsanto paid US$108 million to the family of a worker who died of leukemia.
- In 1988, Monsanto paid US$1.5 million as claim settlement to 170 workers for exposure to rubber additives that resulted in bladder cancer.
- In 1986, W.R. Grace and Co., paid US$8 million for pollution of well water which caused leukemia.

- In 1986, the Bhopal Gas Disaster cost Union Carbide US$350 million for 52,000 claims arising from 2,347 deaths and 30,000 to 40,000 injured.
- In 1983, Jackson township had to pay US$16 million to 350 residents because the township's municipal solid waste disposal facility polluted their water supply.
- At Johns Manville in 1982, US$2 billion expenditure was incurred to settle 52,700 claimants affected by asbestos.

7.1.3 Legal provisions

There are a number of laws in India which contain provisions relating to risks and accidents. A few are listed here and for details the reader is recommended to read the specialised literature.

- The Factories Act, 1948, is one of the oldest legislations, amended subsequently (in 1987).
- The Motor Vehicles Act, 1939 (as amended in 1988).
- The Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989 (as amended in 2000).
- The Public Liability Insurance Act, 1991 (as amended in 1992).
- The Chemical Accidents (Emergency Planning, Preparedness and Response) Rules, 1996.

All these regulations deal with aspects of safety, penalties for non-compliance, schedules and forms. These laws must be adhered to in letter and spirit. It is desirable to design our activities in line with these regulatory requirements. In addition, it is wiser to study similar provisions adopted in other countries to develop foresight.

For example, in the USA, the specifications given in table 3 are observed:

Table 3: Limiting quantities for environmental risk

#	Chemical	Quantity permitted in pounds under RMP (risk management programme) rules.	Toxic end point mg/cum, under the same RMP rules
1	Acetaldehyde	10, 000	Flammable
2	Acrylonitrile	20, 000	76
3	Anhydrous ammonia	10, 000	140
4	Bromine	10, 000	6.5
5	Butadiene	10, 000	Flammable
6	Chlorine	2, 500	8.7
7	Chloroform	20, 000	490
8	Dimethylamine anhydrous	10, 000	Flammable
9	Dimethylhydrazine	15, 000	12
10	Ethylamine	10, 000	Flammable
11	Ethylene oxide	10, 000	90
12	Fluorine	1, 000	3.9
13	Formaldehyde	15, 000	12
14	Hydrogen chloride	5, 000	30
15	Hydrogen fluoride	1, 000	16
16	Isopropyl amine	10, 000	Flammable
17	Methylamine	10, 000	Flammable
18	Methyl hydrazine	15, 000	9.4
19	Nitric acid	15, 000	26
20	Nitric oxide	10, 000	31
21	Oxygen difluoride	-	
22	Ozone	-	
23	Perchloryl fluoride	-	
24	Phosgene	500	0.81
25	Sulfur dioxide	5, 000	0.78
26	Sulfuric acid (oleum)	10, 000	10
27	Toluene diiscocyanate	10, 000	7
28	Vinyl acetate monomer	15, 000	260
29	Vinyl chloride	10, 000	Flammable

- In the USA, the limiting quantities given above (in column 2) are regarding environmental risks. For safety risks, the threshold is brought down to 10-25% of them.
- In India, the regulatory quantities as stated in the MSIHC Rules, 1989, when compared with the above (column 2), appear generally liberal.

To date, 214 chemicals are identified as carcinogenic, but many others too may be placed in that category. Responsibility for the use of all substances lies on the industry using the chemical. While normally a person is innocent until proven guilty, with regard to carcinogenic substances the rule is 'guilty until proven innocent.'

7.1.4 Cancerous chemicals

Chemicals known to cause cancer in humans (based on USEPA 1998) are listed in table 4:

Table 4: Cancer-causing chemicals

#	Chemical name	Sources/uses	Tumour site
1	Arsenic	Natural rock/pesticide	Lung, skin
2	Asbestos	Natural rock/insulation material	Lung, intestine
3	Benzene	Solvent	Blood, bone marrow
4	Benzidine	Over 300 dyes in leather, paper, textiles	Bladder
5	Coke oven emissions	Iron steel mfg	Lung, kidney, prostate
6	Diethylstilbestrol DES	Fertility drug	Breast
7	Direct black 38	Azo dye	Liver
8	Direct blue	Azo dye	Liver
9	Direct brown 95	Azo dye	Liver
10	Hex chromium	Natural rock/pigment	Lung
11	Nickel	Natural rock/plating	Lung
12	Radon	Natural radioactive element	Lung
13	Secondary smoke	Tobacco products	Lung
14	Vinyl chloride	Synthesis of PVC	Liver, lung

- There are said to be about 90 million known chemicals, out of which 7,000 are important. Out of these 7,000, some toxicological data is available on 1,000 chemicals only, and that too after tests on animals.
- The following chemical classes are especially recommended for study due to cancerous effects on hormones: polynuclear aromatic hydrocarbons (PAHs), dioxins, polychlorinated biphenyls (PCBs), heavy metals and pesticides.

7.1.5 Our environment

Hazards can also be caused by air emissions, for example:

1. *Particulates*

Sources: Quarries, unpaved roads, parking, windblown

Effects on health: Lung scarring, difficult breathing, chest pain, coughing, decreased vital capacity.

Effect on vegetation: Covers plants, prevents air and water exchange, reduces growth process, may stunt or kill plant.

Effect on property: Soils and corrodes building materials and electrical equipment. Also soils textiles.

2. *CO*

Sources: Vehicles

Effects on health: Reacts with haemoglobin in blood to reduce the amount of oxygen available to the body; causes headache, dizziness, nausea, vomiting, systemic pain, fatigue, death.

Effect on vegetation: None significant except at very high concentration.

Effect on property: None known.

3. SO_2

Sources: Fuel burning

Effects on health: Increases bronchial constriction, aggravating asthma, emphysema, decreasing lung ventilation.

Effect on vegetation: Highly toxic to plants, yellowing of broadleaf species and needle tip burn of conifers.

Effect on property: Corrosion of metal, of carbonate containing stones including marble, limestone and mortar. Deteriorates textile, leather, fibre, paper products.

4. NO_2

Sources: Vehicles

Effects on health: At high levels, causes pulmonary edema and death. At low levels, effects include emphysema, lung, liver, heart damage, eye-skin irritation.

Effect on vegetation: Defoliating chlorosis and tip and margin burn of leaves, slows growth, reduces photosynthesis.

Effect on property: Fading and loss of colour in textiles, deterioration of cotton, nylon fibres, corrosion of electrical switches.

VOCs may get absorbed in water. The concentration in tap water should not exceed the following, maximum concentration levels (MCL as goal), proposed or final. Table 5 provides data that is useful for monitoring the situation before finally assuming that the water is safe.

Table 5: Maximum concentration levels for VOCs

Compound	Final MCLG mg/l	Proposed MCL mg/l	Final MCL, mg/l
Benzene	0.0	0.005	0.005
Vinyl chloride	0.0	.001	0.002
Carbon tetrachloride	0.0	.005	.005
1,2-Dichloroethane	0.0	.005	.005
Trichloroethylene	0.0	.005	.005
.p-Dichlorobenzene	0.075	.005	.075
1.1-Dichloroethylene	0.007	.007	0.007
1.1.1-Trichloroethane	0.200	.200	.200

7.2 Basic Principles for Avoiding Disasters

Basic principles for avoiding hazardous situations are:

1. Eliminate the hazard. This can be achieved by substituting dangerous substances or processes with simpler ones. For example, in glue, solvent based chemicals are replaced by water based ones.

2. Keep the operation at a distance from the operator, so that he or she is saved from the mishap. For example, using remote control or chain blocks (or robotics).

3. Shield the hazardous substance/process from the worker handling it and the other workers in the shop unconnected with its use. Protect workers by providing personal protection equipment such as dust mask respirator, half face cartridge respirator, self contained breathing apparatus (SCBA), goggles, eye-and-face shield (for corrosive liquid), gloves, aprons, boots, etc.

4. Provide general ventilation or make local arrangements to dissipate fumes, gases, vapours, mists, etc. If gas is liberated from an operation, then arrange for gas suction close to the source of liberation. This can be done by conscious suction, local and north light openings and windows.

5. Other common sense approaches that will avoid accidents are: proper labelling, availability of MSDS, providing washing places, storage care compatibles, refrigeration for flammables, ventilation for volatiles, dyked areas around tanks, automatic closing doors, safe wiring, etc., care during transfer of flammable materials, arranging personal monitoring devices, record keeping and good house keeping.

7.2.1 Priorities

A large number of chemicals are involved in any activity. To streamline investigation, take up some target areas first. The prioritisation may be based on:

1. The toxicity of chemicals. These may be few, but being extremely toxic, they need attention. Examples are benzene, cadmium, carbon tetrachloride, chloroform, chromium, cyanide, lead, mercury, methyl ethyl ketone, methyl isobutyl ketone, methylene chloride, nickel, tetrachloroethylene, toluene, trichloroethylene (TCE); 1,1,1 – trichloroethane (TCA), xylene, etc.

2. The 80/20 materials management rule. Generally a few chemicals of the industry's raw material list, say 20%, will comprise 80% of the total volume. Thus, first examine the 20% segment.

3. Chemicals to which the community or public interest groups are sensitive. These are dioxins, chlorinated solvents, or even malodours. Such chemicals need attention from the point of view of transportation as well.

7.2.2 The disaster management team

For disaster management, a team is necessary. It is desirable if local people are involved in the team. The team must:

1. Know the company policy, purpose, authorities, principal control measures and emergency organisation chart, showing positions and functions.

2. Prepare some descriptions of the expected disaster with a risk statement.

3. Have a map of the plant, office, store showing equipment, medical and first aid, fire control apparatus, shelters, command center, evacuation routes and assembly areas.

4. List and post cooperating agencies along with contact information.

5. Plant warning systems.

6. Establish a central communication centre.

7. Be familiar with shutdown procedure, including security measures.

8. Know how to handle visitors and customers on-site, and people outside.

The following chart in table 6 describes the jobs of the team members:

Table 6: Jobs of teamworkers

Main team member	Support member	Data (as an example)
Engineering (process engineer and instrument control engineer)	Structural, electrical, and plant engineers	Design capabilities e.g., how many coolers are required to remove excess heat, how many pumps are required to deliver the minimum flow, how many relief devices must operate to maintain safe pressure levels?
Scientist	Chemists, physicists and researchers	Kinetics of system e.g., what contaminant can trigger a runaway reaction, or at what temperature does the substance decompose, or what by-product will result when the material is released to air?
Operations	Human error analyst	How the system is actually operated e.g., are the by-pass valves normally kept open to increase throughput, or what happens when the high level alarm sounds, or do operators bypass interlocks to continue production?
Maintenance	Statistician and data bank	Process configurations during maintenance activities and historic data on equipment performance e.g., how often are the instruments calibrated, does the same person calibrate redundant instruments, how often do the pumps require repairs?
Emergency response personnel	Public relations officer, watch and ward	If QRA involves consequence estimation, the team will need data on the emergency response procedures and capabilities; e.g., how quickly the neighbourhood may be evacuated, what fraction of the release would be neutralized and can firefighters extinguish a blaze in that location?
Safety, industrial hygiene	Materials manager	If QRA involves consequence estimation, the team will need data on the hazards of the materials that could be released e.g., at what concentration does this chemical cause irreversible damage if exposure time exceeds 10 min.?

7.2.3 Planning

The members of the disaster management team should ask themselves the following questions:

1) Do we have the material and energy balance for all reactions?

2) Are there side reactions that can generate toxic or explosive conditions, clog critical equipment or cause other dangerous conditions?

3) Are materials of construction specified?

4) Have adequately sized pressure relief devices been provided for normal and emergency situations?

5) Do the storage arrangements address the material incompatibilities?

6) Does the design account for the possibilities of contamination to upset the process?

7) Are there possibilities of cross contamination from one process to another?

8) Are containers sized, to minimise personnel exposure?

9) Has spill control been provided for loading-unloading areas?

10) Can large quantities of hazardous materials be moved easily in the event of an emergency?

11) Whether, commensurate with actual chemicals handled, information is assembled by referring to works of Sax, Perry, Merck, World Bank, Fire Protection Association, etc.?

Preparatory work will include site inspection too. Inspections will be facilitated with:

- Camera and tape recorder
- Electrical testing equipment
- pH paper
- Air sampling equipment
- Devices to measure temperature, noise and light
- Sample containers
- Personal protective equipment relevant to that area.

7.2.4 Hazard risk analysis

Table 7 gives an example of a very simple analysis for hazard identification, vulnerability and risk analysis, using three chemicals: chlorine, ammonia and MIC:

Table 7: Analysis for hazard identification, vulnerability and RA

	Hazard A	Hazard B	Hazard C
1. Hazard identification			
a. Chemical	Chlorine	Ammonia	Liquid methyl isocyanate (MIC)
b. Location	Water treatment plant	Tank truck on local interstate highway.	Pesticide manufacturing plant in nearby semi-rural area.
c. Quantity	2000 lb	5000 lb	5000 lb
d. Properties	Poisonous; may be fatal if inhaled. Respiratory conditions aggravated by exposure. Contact may cause burns to skin and eyes. Corrosive. Effects may be delayed.	Poisonous; may be fatal if inhaled. Vapours cause irritation to eyes and respiratory track. Liquid will burn skin and eyes. Contact with liquid may cause frostbite. Effects may be delayed. Will burn within certain vapour concentration limits and increase fire hazard in presence of oil/ other combustible matter.	Causes death by respiratory distress after inhalation. Other health effects would include permanent eye damage, respiratory distress, and disorientation, Explosive. Extremely flammable.
2. Vulnerability analysis			
a. Vulnerable zone	A spill of 2,000 lb of chlorine from a storage tank could result in an area of radius 1,650 feet where chlorine gas may exceed the level of concern.	A spill of 5,000 lb of ammonia from a collision of a tank truck could result in an area of radius 1320 feet where ammonia may exceed the level of concern.	A spill of 5,000 lb of methyl isocyanate could affect in an area of radius 3300 feet where MIC vapours may exceed the level of concern (assuming that the liquid is hot when spilled, the tank is not dyked, and the MIC is at 100% concentration).

b. Population within vulnerable zone	Approximately 500 residents of a nursing home, workers at small factory.	Up to 700 persons in residences, commercial establishment, or vehicles near highway interchange. Seasonal influx of visitors.	Up to 200 workers at the plant and 1000 children in school.
c. Private and public property that may be damaged	Facility equipment, vehicles and structures susceptible to damage from corrosive fumes. Community's water supply may be temporarily affected given that the facility is its primary supplier. Mixture with fuels may cause explosion.	25 residences, 2 fast food restaurants, one 30-room motel, a truck stop, a gas station and a minimarket. Highway and nearby vehicles susceptible to damage from fire explosion resulting from collision.	Runoff to a sewer may cause an explosion hazard because MIC reacts violently with water.
d. Environment that may be affected	Terrestrial life	Adjacent forest preserve is highly susceptible to forest fires especially during drought conditions.	Nearby farm animals.
3. Risk analysis			
a. Probability of hazardous occurrence	Low – Chlorine is stored in an area with leak detection equipment in 24-hr service with alarms. Protective equipment is kept outside storage room.	High – Highway interchange has a history of accidents due to poor visibility of exit and entrances.	Low – Facility has up-to-date containment facilities with leak detection equipment, and an emergency plan for its employees. There are good security arrangements that would deter tampering or accidents resulting from civil uprisings.

b. Consequence if people are exposed	High levels of chlorine gas in the nursing home and factory could cause death and respiratory distress. Bedridden nursing home patients are especially susceptible.	Release of vapors and subsequent fire may cause traffic accidents. Injured and trapped motorists are subject to lethal vapors and possible incineration. Windblown vapors can cause respiratory distress for nearby residents and visitors.	If accident occurs while school is in session, children could be killed, blinded and/or suffer chronic debilitating respiratory problems. Plant workers would be subject to similar effects at any time.
c. Consequence for property	Possible superficial damage to facility equipment and structures from corrosive fumes. (Repairable)	Damage to highway. (Repairable). Potential destruction of nearby vehicles due to fire or explosion.	Vapors may explode in confined space causing property damage. (Repairable). Damage could result from fires. (Repairable)
d. Consequences of environmental exposure	Possible destruction of surrounding fauna and flora	Potential for fire damage to adjacent forest preserve due to combustible material. (Recoverable in the long term.)	Farm animals and other fauna could be killed or suffer health effects necessitating their destruction or indirectly causing death.
e. Probability of simultaneous emergencies	Low	High	Low
f. Unusual environmental condition	None	Hilly terrain prone to mists, thus creating adverse driving condition.	Located in a 500-year river flood plan.

(Work of the National Response Team as 'Hazardous Materials Emergency Planning Guide' Washington DC, 1987).

It may be seen from the above that conceptually, hazardous risk analysis (a basis for the above table) consists of three major activities listed in table 8:

Table 8: Hazard risk analysis

1	Hazard identification	Collecting information about potential cause of injury to life, damage to property or environment due to such spills or release.
2	Vulnerability analysis	Identifying zones in the community that are susceptible to damage or harm, its topography, wind direction, size and type of land use – residence, employment centres, hospitals, schools, area of sensitive nature, water-supply, power or food
3	Risk analysis	Assessing the probability of release occurring, and calculating the harm to people (fatalities or acute, delayed or chronic illness), damage to property (permanent, temporary or repairable) and damage to environment (permanent or recoverable).

7.2.5 Methods of risk analysis

Design will be of two types, qualitative and quantitative, depending on whether it is related to accidents or routine low level pollution (chemical leaks).

(A) ***Accident risk:***

The first step will be critical inspection of the shop and listing of all the observations in an environment and safety audit document. Narrowing down the field, one should then identify the hazardous characteristics of materials involved. For this, reading the MSDS is essential. The next step is estimating whether accidents are possible (in the shop, in the store or tank-farm, and during the transport and further estimating the consequences of accidents (location, rate and quantification). The accident may assault some target, other than one's own factory, for instance, the neighbouring industry, hospital, school, highway, etc. The degree of this transferred risk may vary from negligible, acceptable to severe. Accordingly, mitigation measures must be designed.

(B) ***Chemical leaks' risk:***

In this assessment, one has to study the combination of qualitative aspects and quantitative aspects. The step of identifying the hazardous characteristics of the materials involved is the same as the earlier exercise. However, deeper study, besides MSDS, is required. Clinical studies, epidemiology, animal studies, LD50 values, cell tissue tests and structural relationships will perhaps clue us on dose-

response. The dose may be oral, dermal or by inhalation. The media may be water, air or soil. The exposure has to be evaluated on lines similar to the MSDS normally given for known chemicals. Knowing the possible adverse effects with values, an overall risk may be quantified by giving rating and weightage to the properties like flammability, toxicity, reactivity, explosivity or corrosivity. Naturally, some population or property will be affected adversely and its measurement will be the risk factor. Risk will have many components, like social preferences, political issues, economic costs, technological feasibility, legal issues, consensus on 'acceptable risks' and finally, the all-encompassing common sense.

Risk analysis can be either qualitative or quantitative. Qualitative is an adequate and simpler task, but quantitative analysis should be done where necessary. Guidelines for decision-making are:

- If quantitative is prescribed by law, then choose quantitative.
- If major hazard is involved, then choose quantitative.
- If large data base is available, then choose quantitative.
- If frequency of occurrence is high, then choose quantitative.
- Qualitative QRA can be used either for small scale, large scale or a small part of large scale industry.

Examples of typical qualitative QRA objectives are decisions which:

- Determine whether placing the process reactor in a containment cell will significantly reduce risk.
- Determine whether a catastrophic failure of the ammonia storage tank could cause irreversible health impacts in a nearby neighbourhood.
- Identify the major risk contributors in a chemical unloading operation, and identify the best way to improve safety.
- Compare three process designs and rank them according to their risk to the community from both facility and transportation accidents.

- Investigate the potential for unconfined vapour cloud explosions resulting from accidents at the flammable storage tank area.
- Determine whether process improvements are needed to reduce the frequency (or consequences) of accidents.

In qualitative analysis, cause and effect are judged by studying historical frequencies and by assessing whether these may be repeated. In quantitative analysis, further estimation is done for the likelihood of frequency and impacts are predicted by using mathematical models. In this method, a number of alternatives can be worked out as cost-benefit ratio and in each option the resultant level of risk is written. Analysis of worst-case and alternative accidental release scenario is required to be done in some cases.

7.2.6 Ratings and ranking

Hazardous situations are created either by chemicals or by the operation of their reaction. Characteristics like flammability, toxicity, reactivity, explosivity or corrosivity on the one hand and the reactor pressure and temperature, the material of construction, the age of the equipment, the skill by which it is maintained so far, the quality of accompanying instrumentation, etc., on the other, play a role in determining the presence or absence of the hazard as well as its degree.

Hazards can be rated in a number of ways.

Fire:

Fire hazard depends on the flammable properties of liquids, gases or volatile solids. The rating is between zero (when material does not burn) to five (when highly flammable) as given in table 9.

Table 9: Fire hazard ratings

Hazardous parameter	Numerical rating of the material				
	1	2	3	4	5
Flammability	Does not burn.	Ignites, if preheated.	Ignites, if moderately heated.	Ignites at room temperature.	Very flammable gas/very flammable liquid.
Reactivity Stability	Stable, even under fire.	Stable, but at raised temperature, pressure unstable.	Unstable, violent chemical change but does not detonate.	If heated, capable of detonating/ exploding.	Readily capable of detonating/ exploding.
Reactivity with water	Not reactive with water.	With water, releases energy but not violently.	With water, violent.	In between.	With water, violent reaction at room temperature, pressure.
Toxicity (*)	Practically non-toxic. LD50 rat 5-15 gm/ kg	Slightly toxic. LD50 rat 0.5-5 gm/kg	Moderately toxic. LD50 rat 50-500 mg/kg	Highly toxic. LD50 rat 1-50 mg/kg	Extremely toxic. LD50 rat 1 mg/kg or less.

Toxicity:

Toxicity is a measure of dose-response relationship. Hazards are (1) carcinogenic: causing cancer or increasing the incidence of cancer; (2) teratogenic: the induction of defects in offspring at birth, which are non-hereditary; and (3) mutagenic: increase in the risk of hereditary genetic defects. The effects may be acute (a rapid response over a matter of hours) or chronic (over some months). The exposure pathways are varied. Measures of toxicity are LD50 value – a dose that causes death to 50% of the population of rats after 14 days, expressed as ug of substance per kg body weight of a rat. (When the dose for a human of 70 kg weight is 15 gm/kg, it is expressed as 'practically non toxic' and when it is 5 mg/kg, it is 'supertoxic').

If we are to compare two processes for selection, on the basis of lower risk, then ratings have to be done. For this, four considerations are required to be applied, as shown in table 10:

Table 10: Considerations for ratings

#	Consideration	Criterion
1.	Magnitude of health exposure	Production in tonnes per year.
		Number of neighbourhood people exposed in 500 m.
		Duration of exposure. (This may change as per market demand.)
		Population group exposed (workers, consumers or public).
2	Magnitude of environmental exposure	Amount of waste discharged. Less the better.
		Number of stacks, outlets discharging. Less the better.
		Frequency of discharge in number of times/time period. Less the better.
		Dwell time after discharge (half life in days) from MSDS. Readily biodegradable or environmentally stable the better.
3	Health effects	LD50 (oral, rats) mg/kg. More mg/kg the better.
		Immediate effects. None the better. Reversible, irreversible in that order.
		Prolonged effect. None the better. Reversible, irreversible in that order.
4	Environment effect	Compatibility with waste treatment, 5-hr IC 50 (mg/lit). Low effect on ETP microorganisms, the better.
		Aquatic toxicity (fish) LC50 (mg/lit), bio-assay test.
		Bio-concentration potential. Ability to concentrate in the fatty tissues of an organism. Less the better.

7.2.7 Design steps

While designing control of chemical hazards, the seven-step formula given in table 11 is recommended:

Table 11: 7-step formula for control of chemical hazards

#	Approach	Example
1	Substitution, intensification and attenuation	Use chemicals or solvents that are less toxic. Reduce inventories and quantities in the process. Change from large batch reactors to a continuous process. Reduce temperature and pressures. Reduce boiling point using vacuum. Refrigerate storage vessel.
2	Engineering designs control	Contain toxic chemicals in closed systems. Design process control features include emergency shutdown. Local exhaust and area ventilation. Dykes, buildings, other equipment and personal enclosures. Aromatic quench systems for exothermic reactions. Operate at process conditions where runaway reaction is not possible.

3	Countermeasures and emergency response	Automatic or remotely actuated water sprays, curtains, foams, etc. Emergency shutdown equipment and procedures. Evacuation and shelter-in-place procedures. Unit and site communication system.
4	Early detection and warning	Personal and area toxic vapour sensors/monitors. Detection and alarm systems.
5	Policies and procedures	Written operation and maintenance procedures. Equipment inspection and test for mechanical integrity. Audits and inspection.
6	Personal protection equipment (PPE) and good housekeeping	Face masks, goggles, hearing protection, aprons, chemical suits. Contain all toxic liquids, vapours and dusts. Provisions for water, steam and other clean-in-place systems. Lines for flushing and cleaning. Sewer systems with provisions for emergency containment.
7	Monitoring and documentation	Prepare in advance the location and type of monitoring. The outcome to be reported and to be continued till situation returns to normal. Documentation to learn from the episodes, and reporting.

7.2.8 Emergency coordinator

The emergency coordinator is advised to adopt the following emergency response procedures:

1. Activate the internal alarm to notify all industrial persons and government agencies, stating the help needed.

2. If there is fire or explosion, identify the nature, source, amount, real extent and if possible its chemical analysis.

3. Assess concurrently possible hazards to human health or environment, considering both direct and indirect effects. Circulate a map 20 x 27 cm showing roads, buildings, entrance, etc.

4. If there is a threat to human health/environment outside the facility, then (a) forthwith notify the local government and the national response center; (b) notify all local authorities if evacuation is advisable.

5. Take all reasonable measures to ensure fire, explosion, release do not occur, recur or spread to other hazardous materials in the factory.

6. Monitor leaks, pressure build-up, gas generation, rupture in valves, pipes, equipment, etc.

7. Provide for treating, storing, disposing recovered waste, contaminated soil or surface water due to this event.

8. Until cleanup procedures are completed, ensure that no waste that may be incompatible with the released material is treated, stored or disposed in affected areas in the facility.

9. Within 15 days of the accident, submit a written report on the accident to the SPCB as per the rules.

While adopting all the above steps, the project proponent should take the surrounding people into confidence, especially if the possibility of fire exists. The emergency plan in such situations should contain:

- Evacuation procedure and counting heads responsibility (both on-site and off-site).
- Role of various plant officials, encompassing both on-site and off-site.
- Role of selected workers covering both on-site and off-site situations.
- The exits, meeting places first and details of the nearest hospitals, vehicles including ambulances for transporting those who are injured.

Fire extinguishers are of various types (*see* table 12) and what is more appropriate to the industry should be reflected in the disaster management plan:

Table 12: Different types of fire extinguishers

Type	Action	Risk
Pressurised water	Cools fuel rapidly	Conducts electricity. Reacts with some chemicals
CO_2	Removes oxygen	Displaces oxygen when used in confined place
Dry chemicals	Interferes with combustion process	In confined places, greatly limits visibility.

7.2.9 Deviation from routine

Episodes occur as a consequence of deviation from the routine operation process. Various approaches are available to forestall the same. A few examples are given in table 13:

Table 13: Approaches to forestall episodes

#	Approach	Explanation
1	HAZOP study. Hazard and operability is the possible deviation from design in a facility using process parameters (as flow, pressure, temperature, reaction rate) as a basis for examination	This is highly structured approach where process parameters such as flow, temperature are examined for deviation from design intent. Deviation may show potential hazard and then attempt how to solve it.
2	FMEA. Failure mode and effects analysis.	Take component by component. Study of process where component-specific failure (*) mode is identified in preliminary recommendations proposed.
3	FTA. Fault tree analysis.	Use graphical binary representation of specific events that lead to an undesired hazardous event. This identifies sequence of events leading to potential hazard. So that hazard reduction is made with respect to process and equipment. (**)
4	What-if study	What-if the operator fails to shut down say compressor 19B type imaginative study
5	Checklist review	In this approach, the process is reviewed by use of a checklist that reflects previous operating experience on similar processes.
6	What-if/ checklist review.	This is a combination of approaches 4 and 5, based on imagination and experience.

***Typical equipment failure modes in FMEA can be failure in the control valve, pump, transmitter, heat exchangers, etc., due to leakage, mechanical failure, etc.**

****In FTA approach, precautions are taken to ensure that faults do not take place at all. Some rectification method is provided, either with manual attendance or automatic fail-safe gadget. Both are not likely to fail simultaneously. Even so, there might be failure. Then what emerges is an accident episode. These faults branched in series should be imagined and then taken care of.**

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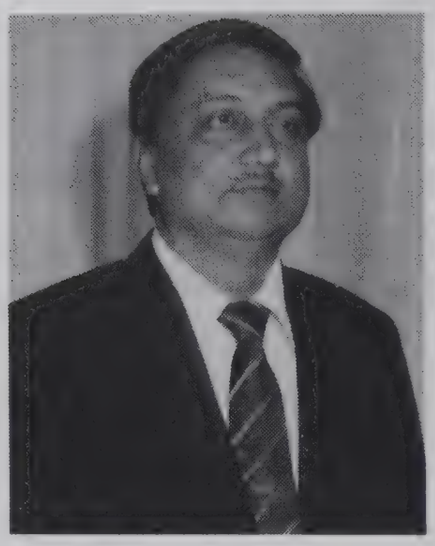

Dr. Dilip B. Boralkar

Dr. Dilip B. Boralkar is one of India's most seasoned environment protection officials. Member-Secretary of the Maharashtra Pollution Control Board, he was recently appointed Adjunct Professor in the Department of Environmental Sciences at the University of Pune. Earlier, in 2003, he was also nominated by the Supreme Court of India in 2003 to its Monitoring Committee on Hazardous Wastes.

Dr Boralkar has 30 years' experience in the field of pollution control and environment protection. After he earned a Ph.D. from Bombay University (in 1979) on the subject of industrial air pollution and its impact on vegetation, Dr Boralkar joined the Central Pollution Control Board and worked in various capacities at Delhi, Goa and Vadodara and rose to the level of Asst. Secretary in 1996. Since joining the MPCB, Dr. Boralkar has undertaken several dramatic initiatives and transformed the MPCB into one of the leading organisations in the field of prevention and control of pollution today.

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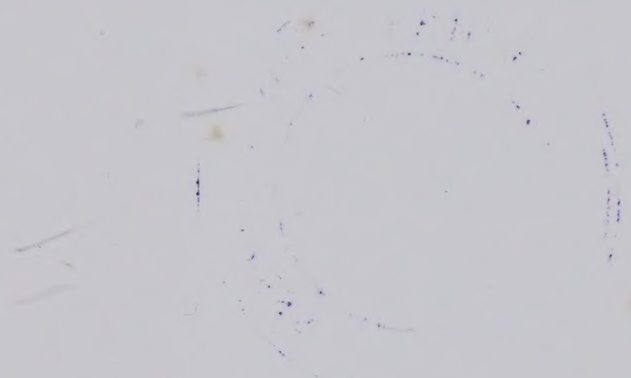

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About *Waste Minimisation*

An excellent compilation of information on how to avoid or minimise the environmental problems by resorting to waste minimisation practices in manufacturing processes. The book provides tips to "leap-frog": especially prioritisation, vendor selection, predictive maintenance, efficiency tricks and designing an appropriate training manual.

– Dr V. Rajagopalan, Chairperson, Central Pollution Control Board

Waste Minimisation supports the arguments of environmental NGOs that constructing landfills is in no one's interest and that the best solution to dealing with hazardous wastes is to stop generating them. Earlier, industry captains could claim they had no solutions. *Waste Minimisation* meets that objection.

– Dr Claude Alvares, Member, Supreme Court Monitoring Committee

Hazardous wastes found dumped in the open environment have been the cause of widespread pollution of ground water, creating drought-like situations in areas traditionally not lacking in water supplies. Public hearings conducted by the HPC in several cities brought forward pleas and representations of distress from affected victims and harsh complaints about lack of response from statutory authorities... This situation cannot be allowed to continue.

– The Supreme Court of India in its order dated 14.10.2003 in writ petition No.657/1995.

A policy on hazardous waste generation should emphasize a commitment to recycling of wastes and materials, and propose incentives for encouraging and supporting recycling. Industries must be given a clear message that they must show concrete and tangible results as far as prevention and reduction of wastes are concerned. If they do not, they should be made to pay a waste generation tax.

– Prof.M.G.K. Menon, Chairperson, High Powered Committee on Hazardous Wastes

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